The impact of domestic electricity supply competition on the application of renewable energy technologies in the UK

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This thesis is dedicated to my parents, who taught me the value of education.

Abstract

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This study investigated the potential for consumer choice in the UK electricity market to lead to increased demand for, and generation by, renewable energy.

To achieve this, a three stage approach was adopted. The first stage evaluated public willingness to pay for renewable electricity, the second stage modelled renewable electricity demand over time, and the third evaluated local potential to meet that demand.

For the first stage, a questionnaire was designed and administered to a section of the population in Leicester who had contact the Energy Efficiency Advice Centre, to evaluate willingness to pay. Results showed willingness was correlated with two attitudinal factors and a variable relating to environmental awareness.

Comparison with a random sample local survey showed no significant difference in willingness to pay for those who could be labelled more aware of energy issues. A comparison with a national survey did show a significant difference between local and national levels of willingness to pay.

These results were used in the second stage to develop model scenarios within the domestic sector of the Dynamic Regional Energy and Emissions Assessment Model (DREAM). Scenarios were developed to predict green electricity demand to 2025, based on willingness to pay for a two percent, eight percent percent and fifteen percent premium. Two further scenarios were developed, based on assumptions of product diffusion and willingness to pay results. Under these later scenarios, renewable sources contributed to 8.87 percent of domestic electricity demand under low growth assumptions, and 12.09 percent under high growth assumptions, in 2025.

Finally, in stage three local demand was linked to local supply through a case study renewable resource assessment for Newark and Sherwood district. Results indicated that, for the low growth and high growth scenarios, the local wind, photovoltaic, hydro-electric, biomass and waste resource was sufficient to meet demand predictions through green tariff uptake.

The research contributed to a body of knowledge regarding environmental purchasing behaviour, energy modelling and local renewable resources, and indicated that consumer willingness to pay for green tariffs could not, alone, deliver UK policy targets.

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Chapter 1: Introduction

This chapter outlines the main aims of the investigation. It briefly describes how the aims of this research relate to policy concerns in the UK. The chapter concludes with a short description of the three stages of research.

1.1 Aims and objectives of the research

This investigation wished to address the hypothesis:

> "consumer choice in the UK domestic electricity market will not lead to an increased demand for, and generation by, renewable energy".

The research aimed to determine the potential for renewable energy in the competitive electricity market, in order to critically appraise the competitive market as a support mechanism to renewable energy policy.

This research aim was delivered through three objectives:

- to measure public willingness to pay for renewable electricity;
- to estimate the level of generation required to meet future green power demand within future electricity demand scenarios;
- to determine the potential for local renewable electricity generation to meet local green power demand through a case study.

1.2 The relevance of the research hypothesis

The UK market for green power was at a relatively immature stage during the period of this investigation. Green power marketing activity began soon after privatisation (1989) but very few products were aggressively marketed. Liberalisation of the domestic market was at the time, lauded as an opportunity for renewable energy sources (Porter, 1997; Stanford, 1998). This research aimed to investigate the potential for delivery of Government targets for renewable energy through green power products in the competitive market.

During this investigation, the UK government introduced a renewable energy policy target of ten percent of UK electricity demand (Department of Trade and Industry, 2000) from renewable energy sources. This was well below the proposed technical limit to renewable electricity market share of twenty percent (Roger, 1995), but targets which have been proposed for beyond 2010 (Performance and Innovation Unit, 2002; Royal Commission on Environmental Pollution, 2000) may have implications for the structure of the electricity industry and the methods of electricity transmission. By investigating possible future green power demand scenarios, this research indicated possible future grid penetration of renewable energy technologies. This is of particular importance in the management of local distribution networks, given the scale of embedded generation implied in the Government target. By relating the green power scenarios to a local resource assessment, this investigation highlighted the problem of renewable energy penetration of local distribution networks.

In general, the UK government remained supportive of renewable energy following liberalisation of the electricity industry. Renewable sources of energy were recognised by the UK government as important within the sustainable development agenda and the climate change strategy (Department of Environment, Transport and the Regions, 2000). Renewables were also seen as crucial in achieving greenhouse gas and carbon dioxide reduction targets (Department of Trade and Industry, 1999). The Royal Commission on Environmental Pollution (2000) incorporated renewable energy within a long-term strategy for carbon dioxide emission reduction, and made reference to the considerable carbon dioxide emission savings for renewable energy generation (compared with fossil fuel sources) when considering the entire life-cycle of energy sources. Given the potential for renewable energy for the UK as a whole (between 250TWh/year and 400TWh/year by 2025 (Energy Technology Support Unit, 1994)), this research contributed to policy discussions on mechanisms to increase the contribution of renewable energy in the competitive market.

In 2001 the UK Government introduced the Climate Change Levy on energy users, with exemption for electricity produced from quality combined heat and power (CHP) and renewables. In 2002 the Renewables Obligation was implemented (see Section 2.4.3 for a detailed description). As a result of these two policy measures, suppliers were required to increase the amount of electricity purchased from renewables and the demand for renewable electricity products increased in the non-domestic sector. These policy measures combined to decimate the voluntary domestic green power market. Suppliers found it far more profitable to sell renewable electricity products to the non-domestic sector, or to use Renewables Obligation Certificates (ROCs) to meet the legal obligation, rather than cash ROCs in to provide additionality for domestic green tariff products. On completion of this research, only one domestic green supply tariff product was providing additionality to the Renewables Obligation.

1.3 A description of the investigation

There were three stages to this investigation. The first stage related to the first research objective: to measure public willingness to pay for renewable electricity. This involved an investigation into the theory of contingent valuation, survey design and statistical analysis. Previous research in the United States was evaluated and compared with willingness to pay research in the UK. A survey was developed, piloted, administered and analysed using a sample of Leicester citizens who had contacted the Energy Efficiency

Advice Centre, to investigate willingness to pay for green tariffs. The results were compared with other surveys which had investigated willingness to pay in the UK.

The second stage of the research related to the second research objective: to estimate the level of generation required to meet future green power demand within future electricity demand scenarios. This stage began with a review of suitable energy models for developing future green electricity demand scenarios. Based on the research requirements, the model was chosen and a sensitivity analysis was carried out. The model was then used to develop several future scenarios, based first on the willingness to pay survey results, and then based on survey results in combination with modelled green tariff uptake scenarios. The results enabled analysis of green electricity demand and the resultant required local renewable energy installations.

In the third and final stage, the third research objective was addressed: to determine local potential for renewable energy to meet local green power demand through a case study. A case study area was chosen, for which no previous renewable energy resource assessment had been completed. The main economically viable technologies were investigated and their potential estimated. This was then related to the resultant required local renewable energy installation which was necessary for the future green electricity tariff scenarios. The purpose was to determine, for a case study area, whether green power demand (predicted via scenario models) could be met through locally sourced renewable energy generation projects.

1.4 Summary

The hypothesis for this research was "consumer choice in the UK domestic electricity market will not lead to an increased demand for, and generation by, renewable energy". The investigation was approached in three stages: an analysis of willingness to pay through a survey, an analysis of possible future green electricity demand scenarios using an energy model, and a renewable resource assessment of a case study area to see whether local generation could match local demand.

Chapter 2: The UK electricity scene and green tariffs

2.1 Introduction

This chapter outlines the historical development of the UK electricity industry, from small scale distributed private generation, through nationalisation and trends for large scale centralised generation, back to privatisation and smaller generating units. The legislation driving UK energy policy is outlined, incorporating international, EU and national legislation. The chapter ends with a discussion of renewable technology in the electricity market, incorporating a description of the previous Government support mechanism (the Non Fossil Fuel Obligation), the current support mechanism (the Renewables Obligation) and recent opportunities for consumers to purchase green power.

2.2 A brief history of the UK electricity industry

The industry structure in the UK could best be described by explaining its historical development before and after recent privatisation and liberalisation.

2.2.1 Pre privatisation

2.2.1.1 Growth in electricity demand

Electricity demand in the late nineteenth century was primarily for public lighting. Some municipalities chose to generate electricity and supply their own areas, but private companies were involved in generation and supply at an early stage. There were problems with the standardisation of supply systems, however, which were not resolved until the Electricity (Supply) Act 1926 (Byatt, 1979).

Load demand increased as technology developments incorporated further uses of electricity, most notably the electric motor. Power shortages in the two winters which followed the end of World War II led to pressure on government to nationalise the industry. The Labour government passed the Electricity Act 1947 to enforce nationalisation of the industry, with the creation of a central electricity generation and transmission company and fourteen supply boards in England and Wales (Hannah, 1979).

2.2.1.2 The nationalised industry

The Central Electricity Generating Board (CEGB) sold electricity to the fourteen (later twelve) Area Boards under the terms of a Bulk Supply Tariff, which was based upon CEGB marginal costs (Green, 1996). The CEGB supplied ninety five percent of power requirements and operated the National Grid (Henriques, 1994). The CEGB also organised the construction of the "SuperGrid" in the 1950's and 1960's, a 275 kV and 400 kV transmission network capable of carrying electricity for longer distances with lower losses. Generation stations were despatched (told when to run) by the CEGB to meet demand and there was almost no privately owned generation connected to the SuperGrid (Henriques, 1994).

2.2.1.3 Barriers to market entrants and renewable energy

Despite attempts to allow greater access to the electricity system through the 1983 Energy Act, the monopoly power of the CEGB was seen as a barrier to the fair trade of electricity by independent power developers, and little development of renewables was achieved by the CEGB itself (see Green, 1996, for a more detailed discussion of the failings of the Energy Act 1983).

The development of renewable sources of energy began to gain credence in the modern electricity industry following the 1970's "oil crises", when security of supply was an issue of concern to the UK Government. The CEGB began to consider the role of renewable energy in the UK electricity supply system, following Government pressure. This was with the aim of reducing dependency of the system on oil.

2.2.1.4 Pre-privatisation summary

The trend over time had therefore been towards large, central generating units with distributed supply and monopoly control. Very little renewable electricity was being generated on the system (excluding large scale hydro power).

2.2.2 Privatisation

2.2.2.1 The main companies created at privatisation

Proposals for the privatisation of the electricity industry in England and Wales were announced on 25th February 1988 in the White Paper Cm 322 (Department of Energy, 1988). It was initially intended that a substantial part (thirty percent) of the CEGB capacity would be transferred to a competing generation company, Little G (later called PowerGen) whilst the remaining capacity, including nuclear stations, would be transferred to a larger private generator, Big G (later called National Power) (Department of Energy, 1988). The larger company would therefore be able to absorb the risk of the nuclear power sector. The Area Boards were to be privatised, and later became known as Regional Electricity Companies (RECs). A new company was to be created to administrate the new industry structure, and operate the high voltage ("SuperGrid") transmission system. This transmission company was to be jointly owned by the Area Boards, and became known as the National Grid Company. Pump storage power plants were also vested in the National Grid Company (Ram, 1995).

2.2.2.2 Nuclear power and the Non Fossil Fuel Obligation

Revelations regarding the high cost of electricity from nuclear power stations led to their withdrawal from the sale (Green, 1996), which negated justification for the size of National Power and the breakdown of the CEGB into an oligopoly. Green and Newbery (1997) have criticised the effect of the duopoly arrangement and the associated market power over electricity spot market price. In a separate paper, Green (1996a) estimated the deadweight losses to the industry due to this duopoly power and the possible reduction in such losses through divestiture, restructuring or increased entry to the generation sector.

(Deadweight losses are those costs to the industry associated with a high equilibrium price, where average prices exceed generation costs.)

In order to ensure that the State-held nuclear power industry had a market for their electricity, final legislation placed a Non-Fossil Fuel Obligation on all Regional Electricity Companies. The excess costs of meeting the obligation were recovered from the customer via a Fossil Fuel Levy (Electricity Act 1989). An industry regulator was introduced to oversee the industry, known as the Office of Electricity Regulation (OFFER). Regulation was primarily introduced because many monopolistic features remained in the industry following privatisation (Ezra, 1993), particularly in the "wires" business (transmission and distribution).

2.2.2.3 Scotland's industry structure

The Electricity Act 1989 also detailed the restructuring of Scotland, where it was proposed that the existing structure remain fairly intact. The two existing boards, South of Scotland Electricity Board and North of Scotland Hydro-Electric Board, were renamed Scottish Power and Scottish Hydro-Electric (vertically integrated, responsible for generation, transmission, distribution and supply) whilst all nuclear capacity remained within State ownership as Scottish Nuclear (Littlechild, 1996).

2.2.2.4 Pool trading and competition

Between the time of publication of White Paper Cm 322 (Department of Energy, 1988) and Vesting Day 1990, there were two other important developments which became part of the legislation to restructure the industry. The attempt to design a system around contracts failed and there was a need to introduce the Pool trading system for England and Wales (Birch, Ozveren and Smith, 1994). This was to be administered by the National Grid Company. Also, competition in supply was announced in late 1989. The intention was to introduce competition in stages, beginning with the 1 MW market (known as the non-franchise market) at the time of vesting (Green and Newbery, 1997).

At vesting, the Electricity Association was created; a trade organisation for electricity industry players. The Electricity Consultative Councils were also replaced by the Electricity Consumer Committees.

2.2.2.5 Privatisation summary

Competition was introduced through privatisation in England and Wales primarily in the generation sector in 1989. The Central Electricity Generating Board was split down into three (National Power, PowerGen and Nuclear Electric). Trading of electricity was enabled through the creation of the Pool. The Non Fossil Fuel Obligation and Fossil Fuel Levy were also introduced at privatisation.

2.2.3 Post privatisation

2.2.3.1 Changes in ownership

After vesting day of 31st March 1990 in England, Wales and Scotland, the created organisations were launched in stages on the Stock Exchange. The vast majority were bought by foreign investors and some capital assets changed hands several times. Some purchases led to a more vertical structure, such as PowerGen's purchase of East Midlands Electricity in 1998.

2.2.3.2 Privatisation in Northern Ireland

Vesting day in Northern Ireland took place on 1st April, 1992. Northern Ireland Electricity became part of the Viridian Group in 1998 (Electricity Association, 2002), and a regulator was created for the Northern Ireland electricity industry, the Office for the Regulation of Electricity and Gas (OFREG), in 1996.

2.2.3.3 Nuclear privatisation

Partial privatisation of the nuclear industry occurred at vesting day on the 31st March, 1996. British Energy plc was created, and comprised the subsidiaries Nuclear Electric Ltd. and Scottish Nuclear Ltd. The UK government retained a "golden share" in British Energy, amongst others.

2.2.3.4 Interaction with the gas market

The UK gas industry was privatised earlier than the electricity sector, and the market had opened to competition in stages. With Government relaxing the regulations on gas fired power stations and the resulting "dash for gas", the interaction between the gas and electricity markets was formally recognised through the merger of the Office of Electricity Regulation and the Office of Gas Supply into the Office of Gas and Electricity Markets (OFGEM) in 1999. In 1998 the UK Government published the White Paper "Conclusions of the Review of Energy Sources for Power Generation" (Department of Trade and Industry, 1998) and placed a moratorium on gas fired electricity generation plant. This was a response to the "dash for gas", the decline in coal's market share in the electricity sector and the corresponding concerns for diversity of supply. The moratorium was lifted in November 2000 (Department of Trade and Industry, 2001).

2.2.3.5 The Utilities Act and New Electricity Trading Arrangements

In July 2000 the Utilities Act received Royal Assent. One major change in the electricity supply industry which resulted from the Act was the separation of supply and distribution licences. Suppliers and distributors were required to be separate legal entities. The Act allowed the Secretary of State to impose an obligation on suppliers to purchase a specific portion of the electricity they supply from renewables. This Renewables Obligation is detailed further in Section 2.4.3 on page 33.

As the Utilities Act (2000) was being implemented, another major change was taking place in the electricity industry's trading system. The Pool and contracts trading mechanisms had been criticised as lacking transparency (Lowrey, 1997) and subject to price-setting by the incumbent generators (Green, 1996a). In March 2001 the New Electricity Trading Arrangements (NETA) were introduced in England and Wales. These trading arrangements were designed with the purpose of delivering a more effective and competitive trading system. The new system was based on bilateral trading, like other commodity markets, and included forward and futures markets, short-term power exchanges, a Balancing Mechanism and a Settlement Process (Office of Gas and Electricity Markets, 2002).

The New Electricity Trading Arrangements reforms have resulted in wholesale electricity price savings, and in the first year of New Electricity Trading Arrangements (March 2001-March 2002) prices fell by twenty percent (Office of Gas and Electricity Markets, 2002). Office of Gas and Electricity Markets (2002) did recognise that these savings had not been fully passed on to the consumer, despite wholesale electricity generation costs accounting for forty two percent of the average domestic electricity bill. See Figure 2-1 for a breakdown of the average domestic electricity bill.

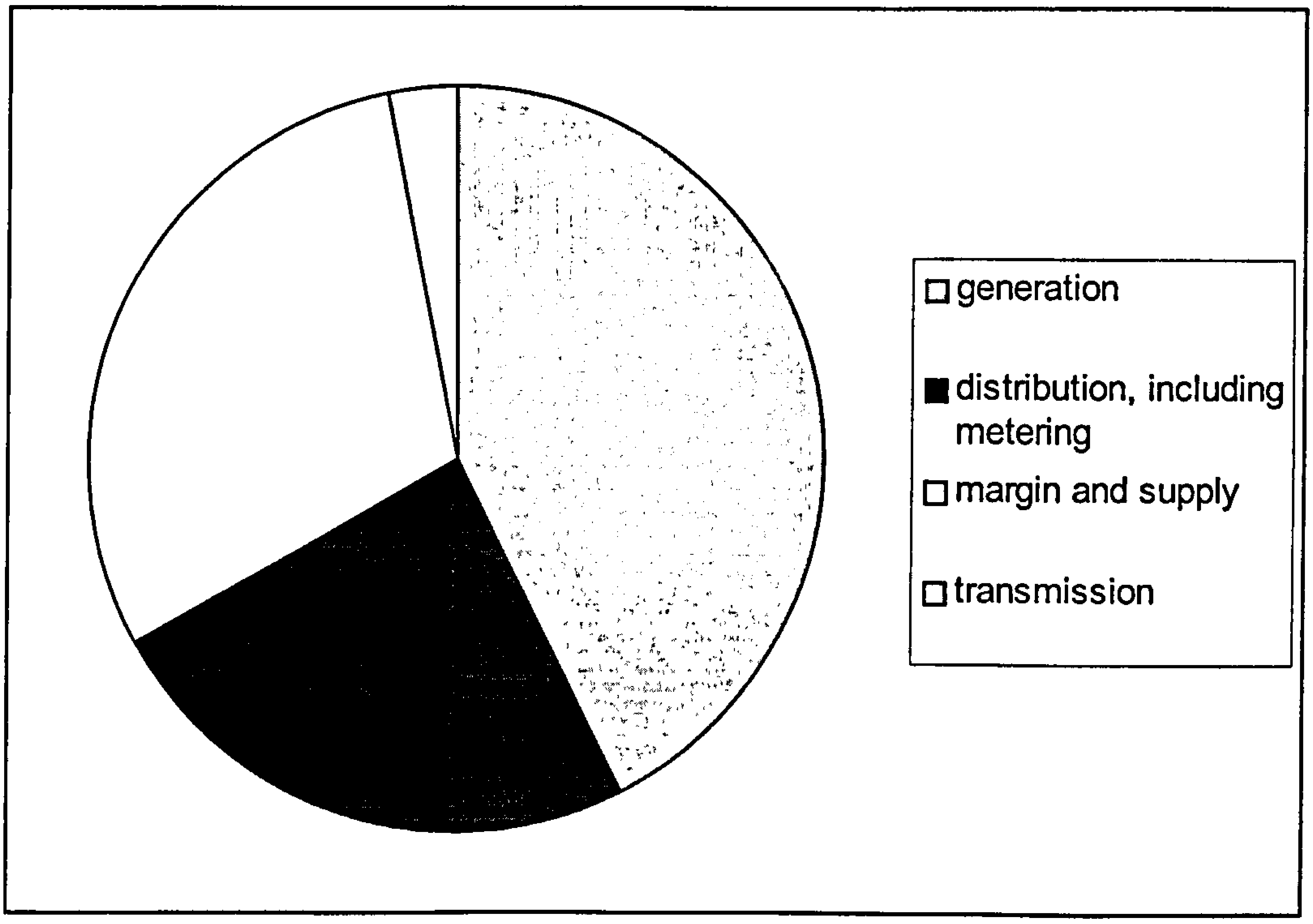

Figure 2-1. The components of an average domestic electricity bill (Office of Gas and Electricity Markets, 2002a)

2.2.3.6 Post privatisation summary

Post privatisation, significant changes have been seen in the market place. There have been numerous changes of ownership and mergers. The electricity supply industry in Northern Ireland was privatised, as was part of the nuclear industry. The Utilities Act (2000) was passed, which introduced the New Electricity Trading Arrangements.

2.2.4 Competition

2.2.4.1 Competition in generation

Competition in generation was introduced at privatisation through the creation of several generation companies. Prior to privatisation there were six major power producers in the UK, rising to eleven in 1991 and twenty three in 2001 (Department of Trade and Industry, 2001). The market share for the major generators in England and Wales is shown in Figure 2-2. Over the period 1998/99 to 2000/01, Innogy (formerly National Power) had seen its share in the generation market halve. The market share of "others" (smaller generation companies) almost doubled over the same period.

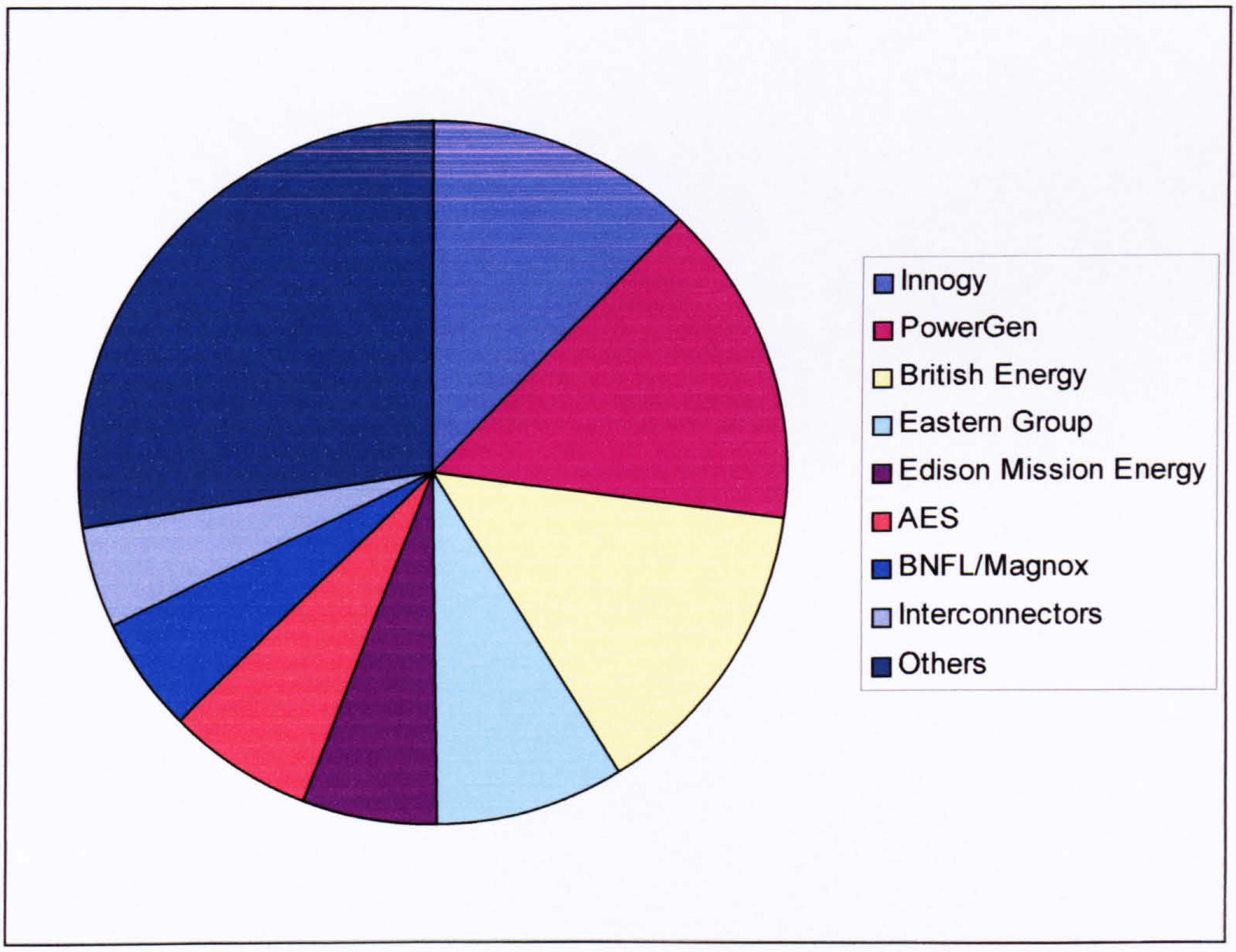

Figure 2-2. Shares of generating capacity in England and Wales, winter 2000/01 (Department of Trade and Industry, 2001a)

2.2.4.2 Competition in supply

At privatisation, First Tier Suppliers were created, to have a duty to supply electricity in their region of operation. These First Tier Suppliers were also known as a Public Electricity Suppliers, and these supply companies were monopoly suppliers to customers in the franchise market. Public Electricity Suppliers in England and Wales were also known as Regional Electricity Companies.

Table 2-1. First Tier Suppliers (Public Electricity Suppliers) created in the UK at Vesting Day (31st March 1990 for England, Wales and Scotland, 1st April, 1992 for Northern Ireland)

Country	Public Electricity Supplier
Northern Ireland	Northern Ireland Electricity plc
Scotland	Scottish Hydro-Electric, Scottish Power
England and Wales	Eastern, East Midlands, London, Manweb, Midlands, Northern, NORWEB, SEEBOARD, Southern, SWALEC, South Western, Yorkshire

Competition in supply was slowly introduced following privatisation. At Vesting Day for the Electricity Act 1989 (England, Wales and Scotland) all those customers with demand greater than one megawatt were able to choose their supplier in these countries. This was known as the non-franchise market.

Any electricity supplier which was not the incumbent First Tier Supplier, or Public Electricity Supplier, was termed a Second Tier Supplier. At privatisation the vast majority of Second Tier Suppliers were Public Electricity Suppliers operating outside their franchise region.

The non-franchise market was extended to 100 kilowatt customers in April 1994. Full deregulation, with the abolition of the franchise market, took place in phases across Great Britain between September 1998 and May 1999. It therefore took eight years to achieve full competition in the electricity supply market.

Market shares, based on output supplied, in England and Wales are shown in Figure 2-3 for the above one megawatt market and Figure 2-4 for the 100 kilowatt to one megawatt market. These two figures show that Public Electricity Suppliers in England and Wales (Regional Electricity Companies) have seen significant decreases in market share in their own region (Department of Trade and Industry, 2001).

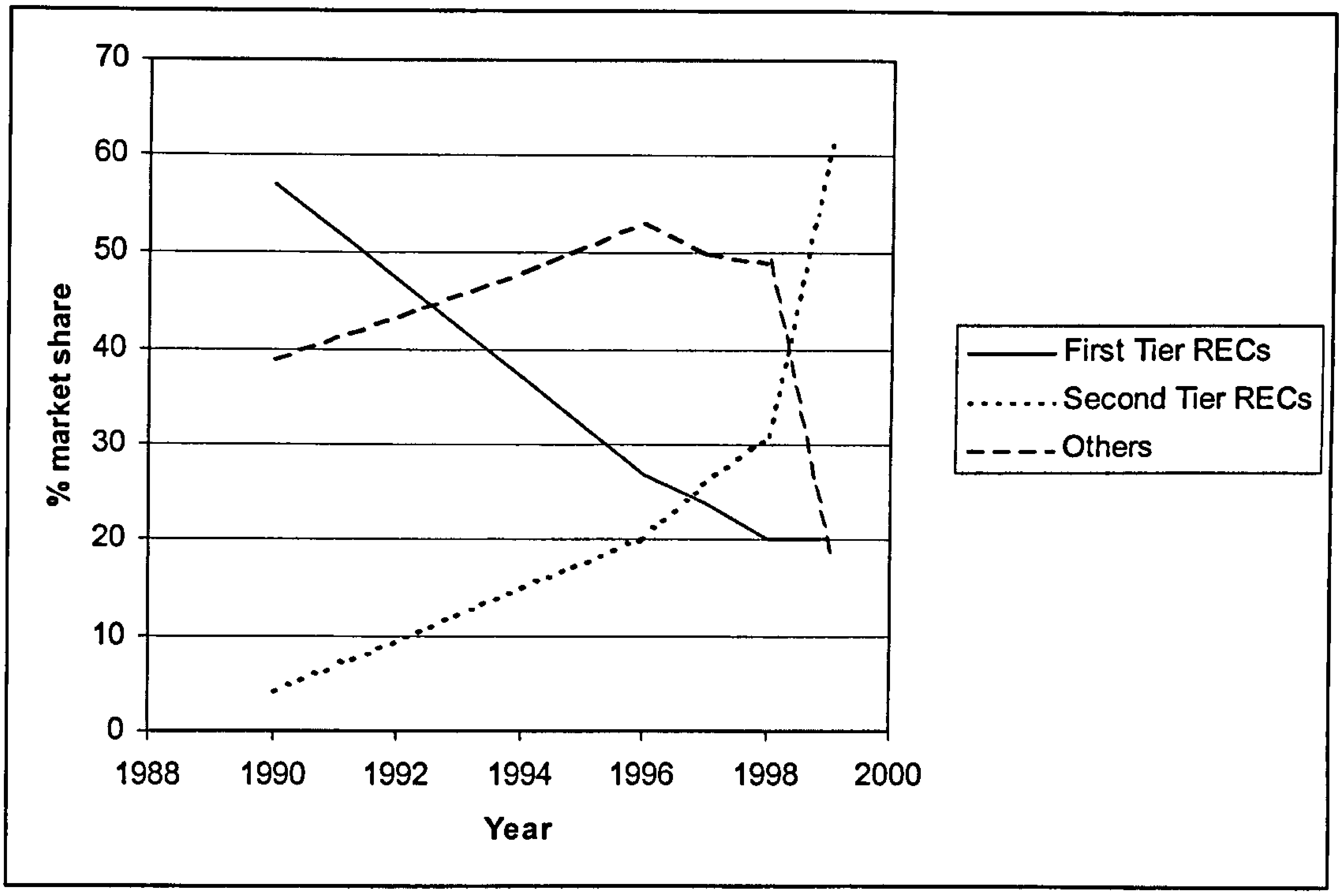

Figure 2-3. Market share based on output supplied in the England and Wales above 1MW competitive market (from UK Energy Sector Indicators (Department of Trade and Industry, 2001))

Competition in the domestic market was completed in phases, by postcode area, between August 1998 and May 1999. By 31 March 1999 Public Electricity Suppliers in England, Wales and Scotland had lost just over two percent of domestic customers in the competitive market (Office of Gas and Electricity Markets, 1999).

In survey work carried out by MORI for Office of Electricity Regulation in December 1998, it was found that switching was highest amongst the middle aged, the professional/ managerial classes, owner-occupiers and those who pay by direct debit (Office of Gas and Electricity Markets, 1999). The main reason for switching supplier was cheaper prices (eighty three percent of survey sample (Office of Gas and Electricity Markets, 1999a)). The reasons given by non-switchers for not changing supplier related to inertia and a perceived lack of incentive to change, as well as a general happiness with their existing supplier (Office of Gas and Electricity Markets, 1999b).

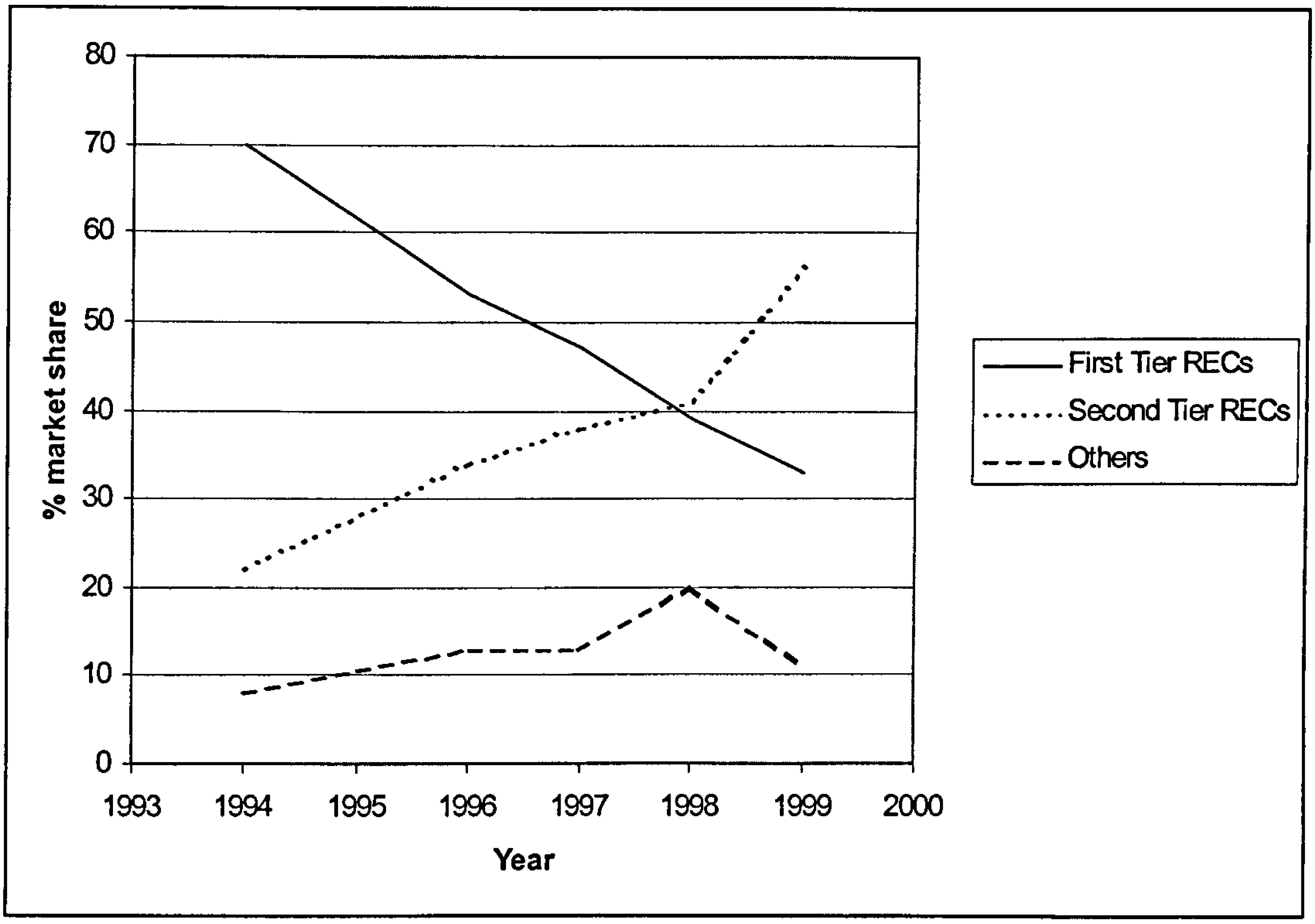

Figure 2-4. Market share based on output supplied in the England and Wales 100kW to 1MW competitive market (from UK Energy Sector Indicators (Department of Trade and Industry, 2001))

By October 2000 nineteen percent of domestic electricity customers had switched supplier at least once (Office of Gas and Electricity Markets, 2001). In 2001 this figure had risen with thirty eight percent of domestic customers having switched supplier least once (Office of Gas and Electricity Markets, 2002a). This compares favourably with the gas market, which had been fully open to competition in domestic supply since 1998, and where thirty seven percent of domestic customers had switched at least once.

2.2.4.3 Competition summary

Competition in generation has seen the market share of the two dominant market players (National Power and PowerGen) gradually reduced. The market share of independent power producers has increased since privatisation.

Competition in supply has gradually seen the market share of first tier suppliers eroded. However, many of the second tier suppliers operating in the market place are first tier suppliers operating outside of their original designated area. The market share captured by new suppliers is relatively small.

2.3 Legislation driving UK energy policy

2.3.1 International energy-related legislation

United Nations Framework Convention on Climate Change (United Nations, 1992)

The ultimate objective of the United Nations Framework Convention on Climate Change was to stabilise greenhouse gas concentrations at a level that prevented dangerous anthropogenic (human) influence on the climate system. Parties to the Convention (those who signed the document) were required to adopt national policies and/or programmes to mitigate climate change. This was based on an equitable approach, taking into account a nation's circumstances, with the aim of returning CO_2 and other greenhouse gas emissions to 1990 levels. Changes to the Convention have been made through Amendments or Protocols, which were adopted at meetings of the Conference of the Parties, for example at Kyoto.

Kyoto Protocol to the United Nations Framework Convention on Climate Change (United Nations, 1997)

This Protocol updated the Convention in detailing the aggregate CO_2 emission reduction levels agreed at the Third Conference of the Parties in Kyoto. These targets varied by country, and had to be achieved within the time range 2008 to 2012: on average a saving of five percent below 1990 levels was expected. The UK was committed through this Protocol to reducing a basket of emissions to eight percent below 1990 levels by the target period.

The Energy Charter Treaty (Energy Charter Secretariat, 1994)

This Treaty has been signed by OECD members, countries of Central and Eastern Europe, and the Former Soviet Union. It was an agreement between Eastern Europe and the West to create open, liberal energy markets and protect foreign investment.

2.3.2 European energy-related legislation and policy documents

The European Commission passed Directives and Communications which Member States then implemented. Directives were legally binding and were required to be incorporated into the legislation of Member States. Communications were less formally binding, although Member States were still required to aim for Communication targets, through programmes and policy implementation suitable to their own circumstances. The European Commission has been concerned at the diverse approach to the energy sector in Europe, particularly given the desire for an internal market in energy goods and services (including gas and electricity). Much of the energy-related Communications and Directives therefore have dealt with creating an European level playing field to remove discrepancies between markets in Member States.

An Energy Policy for the European Union (European Commission, 1995)

This White Paper Communication was based on market integration, concerns regarding competitiveness and environmental protection, the external dimension of supply, and security of supply. With regards to market integration, the prime objective was to liberalise, to create a level playing field, to monitor the internal market and to ensure investment was encouraged. With regards to security of supply and the external dimension, there was a perceived need for Community co-ordination in the event of fuel price shocks. There was also a concern that the European Union would become increasingly dependent on external suppliers unless greater use could be made of indigenous sources of energy. Internalisation of external costs and benefits was seen as the best method of integrating environmental concerns, with efficient energy use of prime importance. The White Paper also recognised that renewables would be the major future sustainable energy source.

Energy for the Future: Renewable Sources of Energy (European Commission, 1997)

This White Paper Communication specified an overall European Union target of doubling the share of renewables to twelve percent of gross inland energy consumption by 2010. Member States were expected to define their own strategy for contribution to the objective, although Member State contributions to the target were not specified. The target was a political, and not a legally binding, tool. The White Paper included an Action Plan to mobilise renewables and a campaign for take-off, including 1,000,000 photovoltaic systems ($1kW_e$ each), 10,000 MW_e of large wind farms, and 10,000 MW_{th} of biomass installations.

The Energy Dimension of Climate Change (European Commission, 1997a)

This Communication noted that CO_2 emissions were estimated to increase by eight percent in 2010 (compared with 1990 levels) if current policies and measures were applied. The European Union was responsible for sixteen percent of global CO_2 emissions but only had six percent of world population. Energy saving was seen as of prime importance - not only for CO_2 benefits but also to reduce energy imports, increase security of supply, and create jobs. The obstacles to greater uptake of energy efficiency were considered to be political and attitudinal barriers. Political determination was suggested as needed to support renewables as well as energy efficiency. Since the bulk of future population growth was expected to occur in towns and cities, where seventy five percent of the current European Union population lived, urban energy consumption was considered a major target. Co-generation would be likely to succeed in a market economy if there were transparent and fair rules with regard to price and competitive gas contracts. Gas was, at the time, rapidly penetrating the electricity market as a major fuel, but its use was expected to peak in 2010. Beyond 2010 this report suggested that, particularly for reasons of security of supply, serious considerations would need to be given to the future of gas in a diverse European energy market.

Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity (European Parliament, 1996)

The internal market was an area in which the free movement of goods, persons, services and capital was ensured. This Directive established the common rules for generation, transmission and distribution of electricity in Europe. It also included rules regarding the organisation and functioning of the electricity sector, access to the market, criteria and procedures applicable to calls for tender and granting of authorisations, and the operation of systems. These rules were written with the view to achieving a competitive market in electricity, and included provision for access to networks. All Member States had adopted legislation implementing the provisions of the Electricity Directive.

Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal market (European Parliament, 2001)

This directive required all Member States to set national targets for renewable electricity consumption. It required schemes for the guarantee of origin to be created, which were different to green certificates. The directive did not propose standard mechanisms for the achievement of national targets, but instead required the Commission to report on the support mechanisms used and if necessary propose a community framework regarding support schemes by 2005.

Green paper: Towards a European strategy for the security of energy supply (European Commission, 2001)

Trends in the basic energy situation in Europe were expected to result in seventy percent of energy requirements being met by imports by 2030. The Green Paper aimed to promote discussion on a new energy policy in light of security concerns and the climate change agenda.

European legislation and energy policy had, in recent years, worked towards harmonisation of rules for electricity markets and developed a European framework for development of renewable sources of energy through target setting at Member State level.

2.3.3 Summary

International legislation which affected UK energy policy had primarily been concerned with climate change and CO_2 emissions. European legislation had attempted to create a level playing field across Europe to enable energy trade. It had also set targets for CO_2 reduction and increased uptake of renewable energy. Much of this international legislation resulted in national UK legislation, in order to implement targets.

2.3.4 UK energy-related legislation

National Government legislation primarily is approved in the format of Acts or Statutory Instruments (known as Orders or Regulations). Local Government has the power to pass local bylaws relating to their geographical area of responsibility. The regulations described below have the most bearing on the electricity industry and the renewables sector, although other legislation such as the Fair Trading Act 1973, the Competition Act 1980, the Restrictive Trade Practices Act 1976 and the Stamp Act 1891, for example, apply in general to business activities.

The Electricity Act 1989

This Act created the privatised structure of the electricity industry in England, Wales and Scotland. The position of Director General of Electricity Supply (DGES) (the regulator) was created, and duties defined. The conditions for the licensing of supply and the duties of supply licence holders were described, as were the conditions placed on Public Electricity Suppliers, and the regulation of supply in general. The Act created the potential for Orders to be enforced regarding the purchase of electricity from non-fossil sources, and for the subsidy of this purchase through a fossil fuel levy. The Act detailed the transfer of existing property of the Area Boards, CEGB, Electricity Council, and Scottish Boards to newly created privatised companies. The initial Government holding of these companies was specified and the floating of such companies was described.

Competition and Service (Utilities) Act 1992

The section on electricity specifically concerned the provision of information to customers, complaints procedures, dispute procedures, and compliance with overall performance standards.

Clean Air Act 1993

This covered dark smoke, smoke, grit, dust, fumes, smoke control areas, control of certain forms of air pollution and general provisions. The Act related to the electricity industry in terms of smoke control areas and sulphur content of oil for engines (affecting emissions levels allowed from embedded generators using fossil fuels).

The Fossil Fuel Levy (Amendment) Regulations 1996

This Statutory Instrument detailed the amount of any payment made by a supplier in respect of the fossil fuel levy.

The Electricity (Non-Fossil Fuel Sources)(England and Wales) Order 1997

This specified (in capacity terms) the must-take for each supplier from various non-fossil sources over approximately 15-20 years, as a result of the Non-Fossil Fuel Obligations. The contracted generating sites received a premium price under the scheme.

The Electricity (Non-Fossil Fuel Sources)(Scotland) Order 1997

This specified the capacity must-take for Scottish Power plc and Scottish Hydro Electric plc from various non-fossil sources over approximately 15-20 years.

The Deregulation (Non-Fossil Fuel) Order 1997

This regulation added a new qualifying arrangement with regard to non-fossil generating capacity purchased by a Public Electricity Supplier, where the system was isolated.

The Air Quality Regulations 1997

This related to the Environment Act 1995 and the duties on Local Authorities to review local air quality. The regulations specified air quality objectives for Benzene, 1.3-Butadiene, Carbon Monoxide, lead, Nitrogen Dioxide, PM_{10}, and Sulphur Dioxide.

The Environmental Protection (Prescribed Processes and Substances). (Amendment) (Hazardous Waste Incineration) Regulations 1998

This implemented an European Council Directive 94/67/EC on the incineration of hazardous waste. This ensured that all incineration processes were prescribed processes designated for central control (rather than local control) and therefore were regulated by the Environment Agency. This was of relevance to the energy-from-waste industry.

The Electricity (Class Exemptions from the Requirement for a Licence) Order 1997

There were two main exemptions from the requirement for a generation licence specified within this Statutory Instrument, relating to the size of generator and whether the generator was located offshore.

There were several exemptions from the requirement for a supply licence as specified within this Order, related to the size of supply, electricity resale, supply on site and supply offshore.

Fossil Fuel Levy Act 1998

This Act changed the definition of electricity subject to Fossil Fuel Levy, to incorporate nuclear and imported electricity.

Utilities Act 2000

The Utilities Act 2000 replaced the Directors General of Gas and Electricity Supply with the Gas and Electricity Markets Authority (GEMA). It established the Gas and Electricity Consumers' Council. The Act created separate licences for distribution and supply, with a condition that distribution and supply licences could not be held by the same legal entity. The Act included provisions for the Secretary of State to impose obligations on gas and electricity suppliers and transporters/distributors to meet energy efficiency targets, and to impose an obligation on electricity suppliers to meet a proportion of their power needs from renewable sources. In August 2000 the Secretary of State for Trade and Industry made use of the powers contained in section 68 of the Utilities Act to enable implementation of the New Electricity Trading Arrangements (Department of Trade and Industry, 2001a).

2.3.5 UK energy policy

Whilst legislation was legally binding, much of UK government policy (and indications of possible future legislation) was contained within a multitude of policy documents. The UK Government has detailed its approach to energy policy within strategies and reports covering such diverse topics as sustainable development, Local Agenda 21, the environment, and energy. Whilst the information contained in such documents is not legally binding for the electricity industry, the Government policy towards the privatised utilities and electricity supply had influenced the decision making process of the private companies and the regulator.

2.3.5.1 Renewables support on environmental grounds

Whilst wishing to support renewable energy on the grounds of security of supply (a less urgent issue in the late 1980's), there was a growing recognition of the environmental benefits of renewable electricity generation within government policy (Department of the Environment, 1990). The main environmental benefits of renewable energies were seen to be the reduction in pollution levels by the replacement of fossil generation.

The Intergovernmental Panel on Climate Change confirmed an increase in global atmospheric CO_2 from pre-industrial 280 ppmv to 356 ppmv in 1994. The radiative forcing due to this CO_2 increase had been estimated at 1.56 Wm^{-2}, and there was significant evidence that these increases were the result of anthropogenic activity (Intergovernmental Panel on Climate Change, 1994). World concern regarding CO_2 levels and the impact on the greenhouse effect had put pressure on the UK, through initiatives such as the United Nations Framework Convention on Climate Change. This resulted in increased targets for renewable electricity generating capacity, from 1000 MW by 2000 (Department of the Environment, 1992) to 1,500 MW by 2000 (Department of the Environment, 1994), and to ten percent of all electricity generated by 2010 (Department of Trade and Industry, 2000).

The atmosphere is a common resource which knows no national boundaries. The complications of enforcing the protection of a shared or common resource was first analysed by Hardin (1968) in his now renowned paper "The Tragedy of the Commons". The problem of air and atmosphere as a shared resource, and global climate change as one consequence of exploitation of the common resource, is the current resource tragedy which requires a solution. Agreement on a political solution is far from being reached, although some targets have been set for the developed countries at a meeting of world leaders in Kyoto (United Nations, 1997). Therefore, concerns regarding climate change have had to deal with problems of policing a global resource.

Johansson, Williams, Ishitani and Edmonds (1996) listed the increased use of renewable energy as one possibility for carbon dioxide emissions reduction, along side four others (more efficient use of fuels, shifting to low carbon fuels and suppressing emissions, decarbonising flue gases and fuels combined with CO_2 storage, and increased use of nuclear). Some of the emission reduction strategies have been incorporated into Government policy (Department of Environment, Transport and the Regions, 2000).

UK CO_2 emissions were primarily (over ninety five percent) produced from the burning of fossil fuels for energy. See Figure 2-5 for details of UK CO_2 emissions since 1990. Since the energy sector was such a major source, the renewable energy industry therefore was seen as having an important role to play in replacing fossil fuels and reducing CO_2 emissions (Department of Trade and Industry, 2000a). Modelling research by Groscurth, Bruckner and Kummel (1993) had indicated that emission reduction strategies would only be economical at significantly higher energy prices, however.

The Government recognised, in "This Common Inheritance" (Department of the Environment, 1990), the added benefits of renewable energy. Aside from a contribution to a strategy to reduce overall CO_2 emissions, renewables had an added benefit in that they were not finite. Unlike fossil fuel resources, the use of renewables did not diminish their future availability. Also, renewable energy could increase the diversity of fuel types in use, thereby increasing fuel security and reducing dependency on single large fuel sources (Department of the Environment, 1990). Realising energy efficiency improvements and increasing the contribution from renewable energy have been listed as part of a sustainable approach to energy supply (Department of the Environment, 1994a).

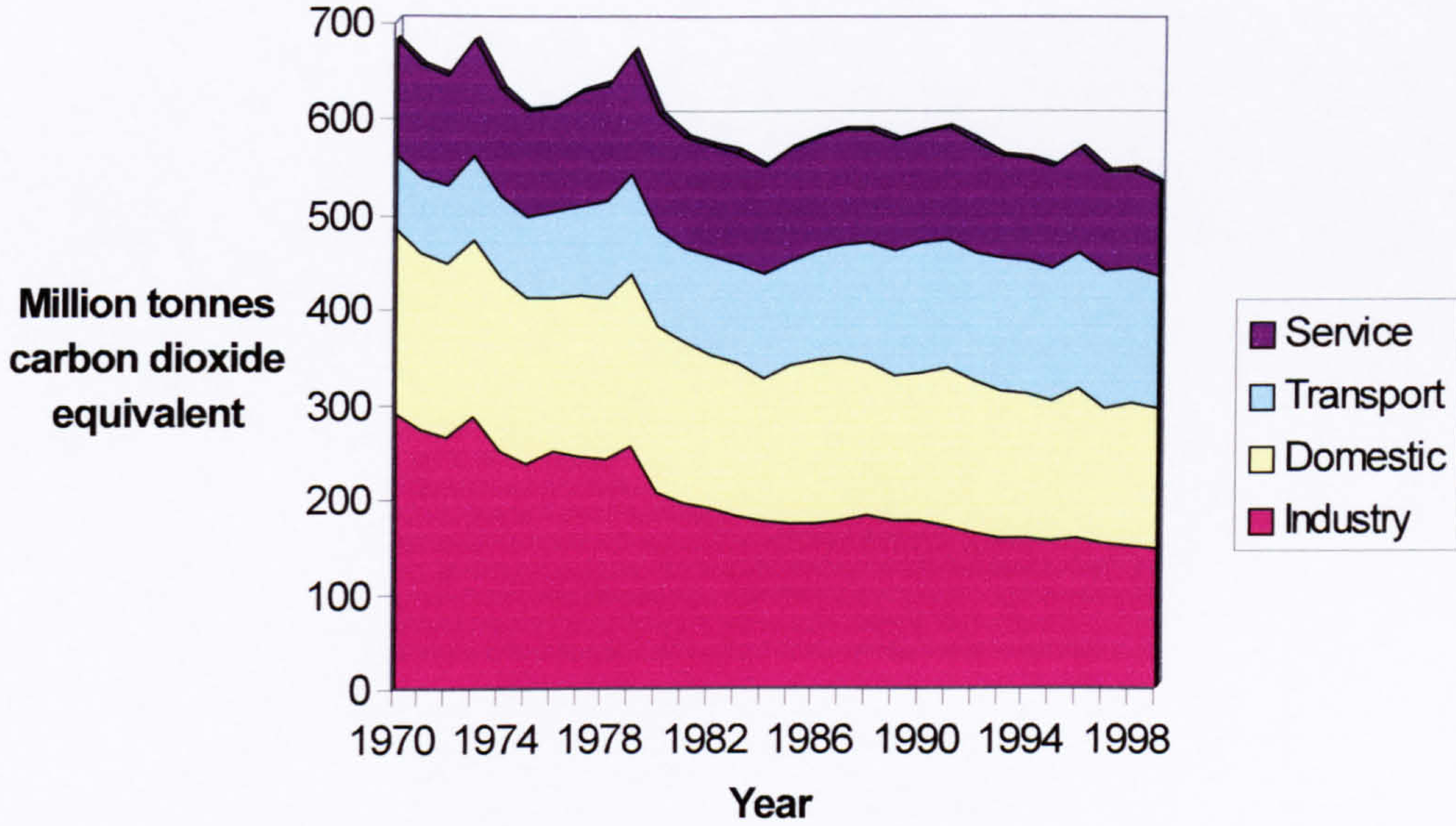

Figure 2-5. UK CO_2 emissions, 1970-1999 (derived from The Environment in your Pocket 2001 (Department for Environment, Food and Rural Affairs, 2001))

It has been calculated that a full range of energy efficiency measures combined with renewable sources of energy would mean renewables could potentially meet all UK energy needs. This included wind, water, photovoltaic and biomass for electricity generation, with solar energy, biogas and solar hydrogen meeting other energy needs (Hill, O'Keefe and Snape, 1995). Despite this potential, and the added benefits, uptake of new renewable energy in the UK has been slow. There has been a lack of awareness regarding renewable energy technologies. Few public policy makers have realised the full significance of global climate change and the contribution that renewable energy could make to improved environmental standards (Kristoferson, 1993).

Development of renewable sources of energy were seen as able to contribute to Government undertakings towards sustainable development and Agenda 21 (Department of the Environment, 1994a). The importance of the renewables industry for both the home and export markets was recognised; for example, the UK 1994 target of 1,500 MW installed renewable energy capacity was estimated to involve sales of equipment and systems of an approximate value of £3,000 million (Department of Trade and Industry, 1995). Other social impacts of renewable energy have been identified, including influence on employment patterns (Ecotec, 1995; Edinger and Kaul, 2000), diversification in rural areas (Grubb, 1995), growth of small to medium enterprises (SMEs) in the renewables sector, the effect on fuel poverty (Department of Trade and Industry, 2001b; Department of Trade and Industry, 2002), the impact on tourism, the potential for community involvement and self-generation (Hinshelwood, 2000), and regional development effects (Bevan, 1996).

The third report of the Sustainable Development Panel (British Governmental Panel on Sustainable Development, 1997) indicated that the short-term approach of competitive markets would not be expected to result in the development of renewable resources to the scale necessary for control of CO_2 emissions. The report also suggested that a Government policy on energy should include promotion of energy efficiency and conservation, incorporate external costs of climate change into energy prices, and provide continued support for non-fossil energy sources.

In estimating the economic feasibility of a sixty percent reduction in UK CO_2 emissions by 2040, Barker (1993) concluded that long term CO_2 reduction came primarily from investment in renewables and energy saving, regulatory changes, lifestyle changes, and improvements in standards. His model included a scenario whereby the renewables sector contributed fifty percent of power generation by 2040 (and gas the other fifty percent) to contribute significantly to CO_2 emissions reduction targets.

2.3.5.2 Renewables support within the electricity supply industry

Very little documentation exists regarding Government policy on the electricity supply industry. One of the most tangible evidence of Government energy policy, including renewable energy, was contained within the Energy Report Volume 1 (Department of Trade and Industry, 1998a). In this report it was stated:

> "The aim of the Government's energy policy is to ensure secure, diverse and sustainable supplies of energy in the forms that people and businesses want, and at competitive prices. The Government believes that this aim will best be achieved by means of competitive energy markets working within a stable framework of law and regulation to protect health, safety, and the environment."

Within the context of electricity privatisation, and increased liberalisation of the traditionally monopoly supply markets, the Government wished to stimulate growth and development in renewable energy. The importance of short term financial support through the Non-Fossil Fuel Obligation mechanism, and the need for price convergence to the market price for electricity, had also been stressed as Government aims.

In 2002 the Government announced a review of energy policy (Department of Trade and Industry, Department for Environment, Food and Rural Affairs, and Department of Transport, Local Government and Regions, 2002). This new policy document was expected in early 2003.

2.4 Renewable technology in the electricity market

Renewable technologies have faced several barriers within the electricity supply industry. One which was identified by developers was the Government support mechanism, the Non Fossil Fuel Obligation. This is described below, as is its replacement, the Renewables Obligation. Renewable energy has been supported in the electricity market, to a limited extent, by green tariffs. The recent experience of green tariffs in the UK is outlined in this section.

2.4.1 Renewable energy and perceived barriers

Within the context of UK Government analysis of the renewables resource, the following technologies have traditionally been considered as renewable (Energy Technology Support Unit, 1994): onshore wind power, offshore wind power, hydro power, tidal power, wave energy, geothermal hot dry rock (HDR), geothermal aquifers, photovoltaic power, active solar energy, passive solar energy, photoconversion, municipal and general industrial wastes, landfill gas, specialised industrial wastes, agriculture and forestry wastes, energy crops.

2.4.1.1 Cost

Some renewable technologies, such as photovoltaics, were considered less mature than others, such as wind, and have not yet been seen as economically viable. Renewable energy technologies tended to involve high capital costs, and lower operation, fuel, and maintenance costs (Energy Technology Support Unit, 1994). This meant the financial viability of schemes was heavily influenced by the discount rate used in financial analysis of a project, and the cost and availability of finance was often a barrier for capital intensive, less familiar technology.

2.4.1.2 The electricity industry structure

The structure of the electricity industry has been based around central power stations, with a high voltage transmission system. Renewable energy does not readily fit into this system, partly due to the intermittent nature of some renewable technologies and the dispersed location of renewable energy sources (Land Use Consultants, 1995). Renewable electricity generation technologies have usually been developed on a small scale, and have been connected to the UK low voltage distribution grid (belonging to the host Regional Electricity Company at privatisation). Electricity produced from such embedded, distributed power systems had been recognised as having financial benefits to the local utility. Careful siting of such plants might have made it possible to defer transmission or distribution investments (Johansson, Williams, Ishitani and Edmonds, 1996). There were also avoided National Grid Company triad charges through the use of embedded generation (during the time of the Pool trading mechanism), and reduced losses on the transmission and distribution networks, which were estimated in one instance at 0.3 p/kWh (ILEX, 1995), to also take into consideration. The industry structure had been perceived as a barrier to renewable energy (Miller and Serchuk, 1996; Ackermann, 1999; Patterson, 1997; Edinger and Kaul, 2000; Elliot, 2000) and the introduction of the New Electricity Trading Arrangements had been accused of severely affecting the economics of renewable energy systems (Bathurst and Strbac, 2001; Milborrow, 2001).

2.4.1.3 Developer perceptions of barriers

Barriers to the development of renewable energy were not limited to the industry structure. A survey of renewable energy developers (Green Land Reclamation, 1995) indicated that the most significant barrier they perceived for renewable energy was the obtaining of planning consent. Agreements on grid connection and Use of System with the Public Electricity Supplier were also suggested by developers as a significant barrier to projects (Green Land Reclamation, 1995). Local environmental impacts relating to the development of renewable energy were often perceived as a barrier, and were a concern held at European level (European Commission, 1996). With particular regard to the UK situation, the NFFO support mechanism for renewables (Non-Fossil Fuel Obligation in England and Wales, Scottish Renewables Order for Scotland, Northern Ireland Non-Fossil Fuel Obligation for Northern Ireland) was criticised as too complex, costly, lengthy and inconsistent (see Williams and Sym, 1995; ILEX, 1997; Milborrow, 1995; Mitchell, 1995 for discussions on the advantages and disadvantages of the NFFO mechanism). The true cost of electricity generated from fossil fuels and the possible internalisation of external costs was supported by several renewable energy associations, in order to provide a more level playing field (for example, British Wind Energy Association, 1996). Lack of clear policy and Government leadership had also been seen as a barrier to further development of new renewable energy technologies (Ezra, 1993).

2.4.2 The Non-Fossil Fuel Obligation

In order to ensure a market for nuclear generated electricity in England and Wales, the government created provision within the Electricity Act 1989 for a fossil fuel levy to be placed on all customers. This subsidy was to raise revenue to support the purchase of expensive nuclear generated electricity which at the time remained in State ownership. Levy funds were allocated to Regional Electricity Companies, to cover the extra cost of nuclear electricity as opposed to electricity obtained through the Pool. At the time, the fossil fuel levy was recognised as a support mechanism which could aid renewable electricity generation in the newly privatised industry. The Secretary of State announced, soon after privatisation, the first round of the Non-Fossil Fuel Obligation. This obligation required Regional Electricity Companies to purchase a portion of electricity from renewable sources. The eligible renewable resources went through a selection procedure following an announcement for applications, with successful projects receiving relatively long term power purchase agreements with a fixed purchase price. A very small fraction of the fossil fuel levy originally went towards the costs of the NFFO renewable electricity purchases. This fraction increased with the success of continuous rounds of NFFO bids. With the rationalisation of Nuclear Electric and Scottish Nuclear into British Energy, and the subsequent privatisation of the nuclear sector in 1996 (with the exception of Magnox stations), the proportion of the fossil fuel levy used to support the nuclear sector declined, as did the overall levy amount as a percentage of customer bills.

The Government's purpose with the five NFFO Orders was to commission 1,500 MW declared net capacity (DNC) of renewable electricity generation (a policy target stated in "Sustainable Development: the UK Strategy" (Department of the Environment, 1994b)). The process proved to be flexible (changes to consecutive Orders included contract length, development time and technology categories), efficient (a total of over 3 GW DNC of contracts were awarded over the five Orders), and competitive (achieving price convergence with traditional generation technologies (Elliott, 1999) and average prices of 2.71 p/kWh for NFFO-5 in 1998, lower than typical purchase prices for RECs in the previous financial year (Mitchell, 2000)).

The scheme had some criticism, in terms of concentration on price competition, which focussed attention on prime sites, led to planning conflict, supported the cheapest (and often non-UK) technology and led to the development of near-market technologies (e.g. wind, landfill gas) but not the emerging technologies (e.g. photovoltaic). It has also been criticised for a lack of successful commissioning, perhaps due to planning system conflict, and incentives to deploy late in the development period.

Various publications by Mitchell provide further commentary on the success of the Non Fossil Fuel Obligation and the problems encountered (Mitchell, 1995; Mitchell, 1996; Mitchell, 1998; Mitchell, 2000; Mitchell, 2000a).

2.4.3 The Renewables Obligation

"The Renewables Obligation (RO) for England and Wales, and the equivalent Renewables (Scotland) Obligation (SRO) for Scotland will place a legal obligation on all licensed electricity suppliers to supply a specified proportion of their electricity supplies from renewable energy sources to their customers in Great Britain" (Department of Trade and Industry, 2000b).

Suppliers had to demonstrate compliance with the obligation to the Office of Gas and Electricity Markets. They were able to do this by presenting Renewables Obligation Certificates (ROCs) which had been issued to qualifying renewable energy generators (which were accredited by the Office of Gas and Electricity Markets, who accredited 335 generating stations, total capacity 1,181,211 kW, in April 2002 (Department for Environment, Food and Rural Affairs, 2002)) and traded on, or by presenting ROCs from any renewable generation systems which they themselves owned. Alternatively they were able to pay a buy-out price to the Office of Gas and Electricity Markets for any part of their obligation which they were unable or unwilling to meet. The details of the operation of the obligation were laid out in The Renewables Obligation Order 2002. This Statutory Instrument allowed banking of ROCs and set the buy-out price at £30 per megawatt hour. Schedule 1 of the Renewables Obligation Order (2002) outlined the percentage obligation for each obligation period, rising from three percent to 10.4 percent over nine years (see Figure 2-6 for the percentage obligation for each period).

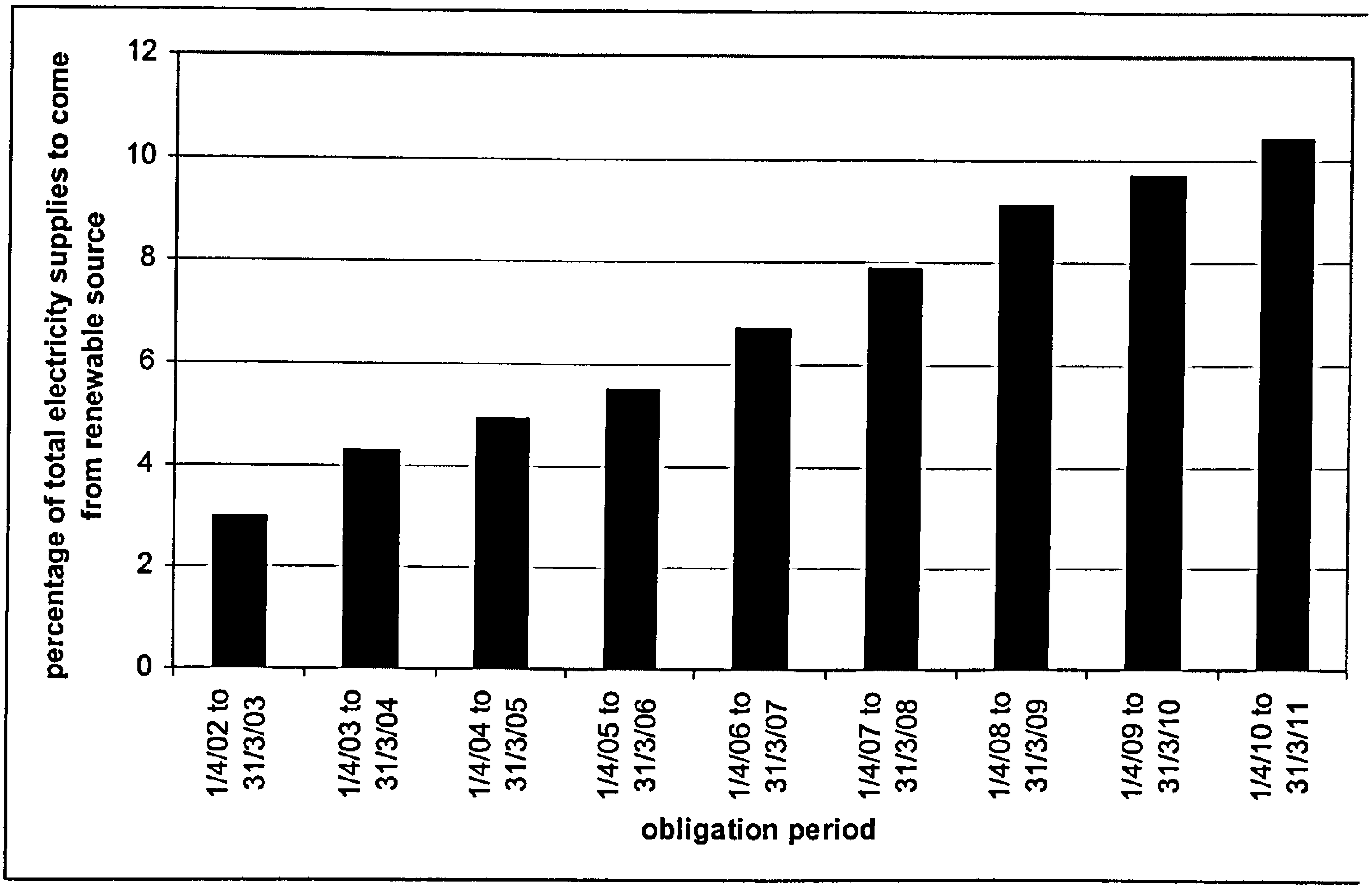

Figure 2-6. Renewables Obligation amount for the obligation periods 2002 to 2011

The Labour Party, in its pre-election manifesto, pledged a target of ten percent of UK electricity supply generated by renewable sources by 2010. This target was re-emphasised in the renewable energy policy documents "New and Renewable Energy: Prospects for the 21st Century" (Department of Trade and Industry, 1999) and "New and Renewable Energy: Prospects for the 21st Century. Conclusions in response to the public consultation" (Department of Trade and Industry, 2000). The Government proposed the Renewables Obligation as a means of delivering on the ten percent target, with the cost of this obligation directly passed on to consumers by the supply companies. Legislation to enforce this obligation was part of the Utilities Act 2000, as well as being subject to its own legislation (The Renewables Obligation Order 2002). This obligation-type policy was seen by the Government as complementary to green tariffs. New electricity trading arrangements did not encourage long term financial security for renewable power producers, however, and these policy changes may have made it more difficult for small companies to secure the necessary capital to develop renewables projects.

2.4.4 Green tariffs in the UK electricity supply industry

2.4.4.1 Competition

The final stage of electricity supply liberalisation in the UK took place in 1998. Rolled out in stages, it allowed all electricity consumers to choose their supplier. This complete deregulation was not expected to result in immediate effective competition in electricity supply. Regulation was expected to continue, albeit in a different format (Department of Trade and Industry, 1998b) in order to protect consumer interests. Powers of regulation continued through the Utilities Act (2000) and the Director General of Gas and Electricity Supply (DGES) Callum McCarthy.

2.4.4.2 Incentives to suppliers to offer "green" tariffs

Whilst immediate effective competition was not expected, increased and fierce competition between incumbent suppliers for domestic customers was most likely. It was expected that this competition would not focus on price alone, but would also incorporate service differentiation (Jennings, 1996; Sigsworth, 1997; Energy Saving Trust, 1997; Flavin and Lenssen, 1994). This service differentiation could take the form of a green tariff to support renewable electricity. There was evidence in the UK electricity market of service differentiation occurring - with loyalty/points schemes, ancillary services such as Internet services, collaboration with other retailers, and a greater variety of tariffs than those available prior to the 1998 domestic sector liberalisation.

Patterson (1996) and Lovell (1998) had both indicated that competition in the electricity market could result in attempts to "brand" the product. This would give the consumer, through choice of purchase, the opportunity to influence providers into considering the environmental impact of electricity sources. Deregulation in the UK has also given suppliers the opportunity to exploit particular sectors of the market, such as the "green" consumer. The renewable energy industry was optimistic that the liberalisation of the domestic electricity market would result in the creation of green electricity suppliers and new green tariff schemes (for example Kettle, 1997; World Wide Fund for Nature UK, 1997; Patterson, 1996; Hodgson, 1997; Jennings, 1996; Porter, 1997; Stanford, 1998).

2.4.4.3 Existing offerings

In 2002, there were eight green tariff offerings accredited under the Future Energy Scheme (a labelling scheme administered by Energy Saving Trust). Other schemes were available in the market which were not accredited (such as Green Energy 10 and Green Energy 100 from Green Energy UK (plc); Green Power from Servista; Juice from npower; and Ecotricity from Ecotricity). Some offerings were available at no premium or a relatively small premium in comparison to conventional electricity prices.

2.4.4.4 Low uptake

In the UK, despite low premiums, perceived customer interest in willingness to pay more for renewable electricity (Parliamentary Renewable And Sustainable Energy Group, 1996; Colbourne, Lorenzoni, Powell and Fleming, 1999; Ecotec, 1996), and a highly competitive market with gradual growth in the number of customers changing supplier, a disappointing number of domestic customers had changed to a green power product (45,150 in December 2001 (GreenPrices, 2002)). This "failure" of green marketers to capture a larger proportion of the market could be due to:

- Cost; repeated surveys of electricity consumers indicated that cost was the primary concern of switchers (seventy six percent listed cost as their top reason when asked what influenced their decision to switch electricity supplier in 2000 (Office of Gas and Electricity Markets, 2001)).

- Lack of marketing; the marketing effort from those companies offering green products has been disappointing. Lipp (2001) and Komor (2002) suggested that this could be due to the mindset of the suppliers who were emerging from a history of monopoly supply and who were not yet customer oriented or experienced in marketing, or due to the perception among suppliers that this niche market was relatively small and therefore not able to make a suitable return on any marketing effort, or due to the fact that any significant consumer interest could overtake the limited green electricity supplies.

- Government policy; since liberalisation of the domestic electricity market in 1998 there were several policy announcements (such as the Utilities Act (2000), the Renewables Obligation (Department of Trade and Industry, 2000b), the Energy

Review (Performance and Innovation Unit, 2002), and the energy policy review (Department of Trade and Industry, Department for Environment, Food and Rural Affairs, and Department of Transport, Local Government and Regions, 2002)). Until these policy details were formulated and finalised there was significant risk to the suppliers in aggressively marketing a product which legislation or policy may subsequently make obsolete.

Despite the relatively small number of green electricity customers in the UK at present, the perception that consumer choice would support renewable energy (Porter, 1997; Stanford, 1998), and the perception that the market segment willing to pay more for renewable electricity was a significant size (Colbourne, Lorenzoni, Powell and Fleming, 1999; Parliamentary Renewable and Sustainable Energy Group, 1996; Farhar, 1993; Farhar, 1996; Farhar and Houston, 1996; Farhar and Coburn, 1999; Farhar, 1999; Ferguson, 1999; Roe, Teisl, Levy and Russell, 2001) provided the motivation to this investigation.

Following the development of the research rational, the Climate Change Levy and the Renewables Obligation came into effect. The result was an effective collapse of the voluntary domestic green electricity market. The Climate Change Levy encouraged business energy users to purchase levy exempt electricity produced from renewable sources, which resulted in non-domestic demand for green electricity reaching levels close to supply levels. The Renewables Obligation required suppliers to purchase a certain percentage of their electricity from renewable sources and, despite OFGEM guidelines on green tariffs and additionality, only one green supply tariff in late 2002 offered additionality to the Obligation. Those suppliers claiming green supply products were not guaranteeing additionality of their products through the retiring of ROCs. However it was possible that, despite the policy changes, there was an interest in (and willingness to pay for) green tariffs in the domestic market.

2.5 The research design

The research design comprised three parts. The first was an investigation into willingness to pay for green supply tariffs. Based on the results of a willingness to pay survey, several model scenarios were then developed. These scenarios aimed to estimate tariff uptake, and hence new renewable installed capacity, over time. The third stage of the research was a case study renewable resource assessment. This resource assessment was carried out in order to determine whether the new renewable capacity required in the energy model scenarios could be installed locally. This was motivated by results of a green supply tariff offering in the United States, where a high level of uptake was achieved where the supply came from a locally installed renewable energy development (Traverse City; Holt, 1997).

2.6 Summary

The UK electricity industry began during the late nineteenth and early twentieth centuries. The government nationalised the industry in 1947 following supply pressures in the post-war era. Following the 1970s "oil crisis", the government put pressure on the Central Electricity Generating Board to consider renewable energy supplies. In 1989 the industry was restructured and privatised in England, Wales and Scotland (in 1994 privatisation occurred in Northern Ireland). At privatisation the nuclear capacity remained in State ownership and a mechanism for support of the purchase of nuclear power was extended to also support renewable energy. This mechanism became known as the Non Fossil Fuel Obligation, and operated from 1990 to 1998. Over the same period, competition was introduced to electricity customers in stages until all domestic customers were able to choose their supplier by 1999.

Legislation and policy at the International, European and national levels had emphasised the contribution which renewable energy could make to a climate change strategy as well as to diverse and secure energy supplies. The UK government had set a target of ten percent of electricity supply from renewable energy sources by 2010. The Non Fossil Fuel Obligation support mechanism had a stated aim of improving the economic competitiveness of renewable energy. The replacement support mechanism, the Renewables Obligation, had a stated aim of achieving the ten percent target. Green tariff options sat within this historical context of a competitive market structure with large industry players, and a government policy of a ten percent target to be delivered through the Renewables Obligation.

At the beginning of the research period, a ten percent renewables target was a manifesto pledge for the Labour party, and domestic supply competition was still being phased in. The Labour government then adopted the manifesto pledge as a policy target, and formulated a mechanism for delivery of that target. The mechanism (the Renewables Obligation) became legally binding. The competitive electricity market in England, Wales and Scotland was seen as a success, with significant levels of customer switching.

The research design at first focussed on the potential for green tariffs in the market place to contribute significantly to the legally binding obligation of ten percent of all electricity from renewable sources by 2010. As policy shifted, and the voluntary green tariff market collapsed, the emphasis changed to consider the contribution which green supply tariffs could make to a ten percent target if guaranteed additionality was part of the product design.

Chapter 3: Willingness to pay for electricity from renewable sources

3.1 Introduction

In order to address the hypothesis of "consumer choice in the UK domestic electricity market will not lead to an increased demand for and generation by renewable energy", it is first necessary to consider the extent to which consumer choice supports green tariffs. This chapter addresses this concern.

The chapter concentrates on the principles of green pricing and willingness to pay. The use of contingent valuation method to measure willingness to pay is discussed. Results of contingent valuation method surveys in the US are then highlighted. In comparison to the US, much less work on willingness to pay has been done in the UK. A brief overview of existing UK willingness to pay surveys will be given. The results of a large local willingness to pay survey will then be presented.

3.2 The contingent valuation method

Past research had attempted to put a value to renewable electricity, primarily from the view of the value of embedded generation or the value of pollution reduction. For example, ExternE, a project which evaluated the externalities of energy, looked at external costs of electricity generation by coal, oil, natural gas, orimulsion, nuclear, biomass and wind in the UK. The externalities estimated for this study were dominated by the effects of air pollution on public health, and climate change. Impacts for renewable technologies were much lower than for fossil fuels (Berry, Holland, Watkiss, Boyd and Stephenson, 1998). The Energy Technology Support Unit commissioned a report by ILEX (1995) to determine the possible value of embedded generation to the local electricity supplier. The results indicated embedded generation had a value of 1.09 - 1.18 p/kWh above the Pool Purchase Price (the price of electricity set in the market place within the Pool trading mechanism).

Willingness to pay surveys had taken a different approach to valuing renewable electricity, by asking the consumer to place a price on supply. This approach of stating a preferred price for a non-marketed good was given the term contingent valuation. A non-marketed good, or private good, was defined as a good which was not routinely bought or sold on a market. In the case of renewable electricity, it is true that electricity was bought and sold, and that consumers gained a utility from this good. Renewable electricity provided the same utility as brown electricity, what was not traded was the perceived benefits of the renewable energy source (which may be environmental or psychological).

In the case of renewable electricity, contingent valuation aimed to determine the perceived economic value of the non-marketed aspects of this good. A willingness to pay survey using the contingent valuation method therefore would ask respondents to place a monetary value on the good in question, in this case renewable electricity. Because electricity was traded, the emphasis was on the value of the non-marketed aspects of renewable electricity and the premium over and above existing electricity market prices which respondents were willing to pay.

The environmental benefit of renewable energy was a public good. By purchasing under a green tariff, the customer benefited from that public good (better air quality, reduced climate change etc.). However, customers who did not choose a green tariff still benefited from the public good. Avoiding payment but reaping the benefit has been termed free-riding (Wiser, 1998). The potential to free-ride can affect stated willingness to pay, since there is no incentive to free-ride in a hypothetical questionnaire situation but incentive to free-ride exists when faced with an actual product which provides public goods.

Economic theory would hypothesize that individuals maximised their utility whilst minimising cost, and that therefore individuals have a strong incentive not to contribute to the provision of a public good through the purchase of a private good at a premium cost. However, individuals do contribute to public goods, although it is not clear whether they do so with the aim of supporting that public good. Benefits may instead be perceived as psychological self-interest, such as social pressure, displaying personal wealth, or the self-satisfaction of "doing the right thing" (Wiser, 1998).

The contingent valuation method has been criticised as a method of estimating economic value due to the complex motivations on respondents. Respondents may receive incentives to misrepresent values under hypothetical contingent valuation conditions, in the belief that this will affect the provision of the public good. This is known as strategic bias (Perman, Ma, McGilvray, Common, 1999). A second set of incentives related to whether people really explored all preferences and made good choices in the hypothetical situation presented (Byrnes, Jones and Goodman, 1999). Thirdly, as discussed above, the potential to free-ride could motivate respondents to mis-represent their perceived economic value of non-marketed goods.

Criticism of the contingent valuation method has been an effective tool in improving the method and its use. Despite its remaining shortcomings, a lack of any alternative method for evaluating, in monetary terms, environmental non-traded goods meant that the method was likely to remain a commonly used tool by academia and government agencies around the world. This has been demonstrated by the development of the Environmental Valuation Reference Inventory. This is an on-line database of contingent valuation method results being developed by several countries in partnership, at URL http:// www.evri.ec.gc.ca/evri/ (Environmental Valuation Reference Inventory, no date).

3.3 Willingness to pay experience from the US

Green consumerism, and green tariffs, were a relatively new concept for the UK electricity supply industry, since competition in supply and product differentiation did not begin until liberalisation of the supply sector in 1998. The United States had more experience in this area. Useful comparisons could therefore be made with the US experience of willingness to pay surveys and green tariffs.

3.3.1 Uptake of green tariff offerings

The first green tariff programmes in the United States were initiated in 1993 (Wiser, 1998). Green tariffs were categorised into three types.

Green rate or tariff
Participants pay based on how much green electricity they use. This could relate to energy or capacity.

Fixed fee
Participants pay a fixed monthly amount regardless of the level of energy use. This may be for installation of renewables.

Contribution
Participants pay a contribution towards a fund for investment into renewable energy. (Holt, 1997a).

In each US state, electricity restructuring had gradually moved towards retail competition. Some states and utilities conducted pilot programmes prior to full competition, including New Hampshire and Massachusetts. The pilot in New Hampshire began in 1996, and allowed a limited number of customers from all customer types to be involved (Holt, 1997b). The pilot was arranged such that participants in the programme saved at least ten percent on their bill. At least six suppliers in the pilot offered customers green products.

Some of these were not renewable electricity products, and the environmental products were criticised in terms of the claims made in marketing these items (Holt, 1997a; Wiser, Fang, Porter and Houston, 1999). The actual uptake of green tariff options in this pilot was not known, but a survey by the New Hampshire Public Utilities Commission indicated that twenty percent of respondents thought that the environmental message within marketing had strongly influenced their supplier and product choices (Wiser, 1998). Renewable energy had a strong influence for seventeen percent of respondents (Wiser, Fang, Porter and Houston, 1999). In the pilot, which ran over two years, customers had to volunteer in order to take part. Forty percent of those who volunteered to take part did not switch supplier during the lifetime of the pilot. Two market research studies, which came after the pilot, indicated that some participants found it difficult to make comparisons between suppliers on the basis of information supplied, and that the level of marketing had been overwhelming (Holt, 1997a). This may partly explain the high level of non-switching in a market place which awarded significant financial saving to switchers.

The trial in Massachusetts was more controlled, and designed by the incumbent supplier Massachusetts Electric Company. Suppliers had to bid for the opportunity to take part in the pilot, with the emphasis on price and service cost choice (Environmental Futures, 1997). A green option was specifically requested by the Massachusetts Electric Company. The pilot began in January 1997, and all switching options offered a cost saving in comparison to remaining with the incumbent supplier (Wiser, Fang, Porter and Houston, 1999). Domestic and business customers were able to subscribe to the pilot, and although most switchers chose the lower price options, thirty one percent of domestic and three percent of business customers who switched chose a green option (Wiser, 1998). Given the number of domestic customers subscribing to the pilot, only 3.5 percent of all Massachusetts electricity consumers actually switched, however (Wiser, Fang, Porter and Houston, 1999).

One of the first states to launch full retail competition was California, in March 1998. Over 200 suppliers registered to take part in the market, with very little opportunity for cost savings through switching. The market rules had resulted in a low price offer from the incumbent utility (Wiser and Pickle, 1998) and competition was therefore focused on value-added products, primarily green power (Wiser, Fang, Porter and Houston, 1999). The California Public Utilities Commission indicated that one year on, April 1999, one percent of residential, 3.1 percent of commercial and almost twenty percent of industrial customers had switched supplier (Green Power Network, 1999). It was estimated that seventy five percent of switchers were using a green power provider in 1999 (Harmon, 1999). This was partly due to Enron and Commonwealth switching all of their customers to green power products, in order to benefit from state subsidies (Wiser, Fang, Porter and Houston, 1999). The vast majority (ninety five percent) of new capacity installed to meet green power demand was wind. Seven hundred MW of existing renewable capacity was being traded through the Californian green power exchange, with twenty MW of new capacity supporting the competitive markets in California, Pennsylvania and New England. A further seventeen MW of new capacity was being marketed by Bonneville Power Administration (Bird and Swezey, 2000). The power crisis in 2000-1 in California forced some suppliers out of business as wholesale prices soared, and many customers were returned to their default utility providers (Cave, 2001). Market opportunities for renewable generators all but disappeared as the Power Exchange ceased trading and market entry was limited following the repeal of direct access in September 2001 by the California Public Utilities Commission (California Energy Commission, 2002). The California situation was further complicated by the collapse of a major utility, Enron, which was operating in the state.

Other US states were at different stages in the development of competition in retail electricity. Uptake of green tariff products in the domestic sector varied from zero to 7.3 percent (Wiser, Bolinger, Holt and Swezey, 2001). Experience in the US had indicated that market rules affected the number of switchers (in terms of the retail price, the possible savings under market rules, and the ease of switching), and that customer awareness, marketing efforts and availability of renewable electricity constrained green tariff uptake (Wiser, Bolinger, Holt and Swezey, 2001).

An analysis of new capacity installed to meet demand for green power in the US clearly indicated that the vast majority of renewable capacity (ninety five percent) for green tariffs existed prior to green marketing and that green power retailing had resulted in only thirty seven MW of new installed renewable capacity (Bird and Swezey, 2000).

Experience in the US therefore showed that, for the green tariff, fixed fee and contribution programs available, actual uptake of products in the market has rarely exceeded five percent of eligible customers.

3.3.2 Willingness to pay survey results

In 1997, Wiser, Pickle and Goldman raised the question "will emerging green markets be a sufficient source of support for renewables absent other forms of renewable policy?" This research attempted to address that question in a comprehensive way. In the US, several attempts had been made to measure the size of these "emerging green markets" (Wiser, Pickle and Goldman, 1997). These willingness to pay surveys are now discussed.

In reviewing social and behavioural aspects of energy use, Lutzenhiser (1993) found a range of attitudes correlated with conservation behaviour (feelings of obligation, belief in importance of conservation, belief in science, belief in importance of individuals, comfort and health issues). The research literature also showed information, particularly feedback, was related to energy behaviour, and that energy behaviour was related to household life-cycle (family age and composition), and income,

A number of national and state surveys in the United States had considered public opinion on energy and environmental policies. Farhar (1993) completed secondary analysis on almost 600 surveys in 1993, and more than 700 polls in 1996 (Farhar, 1996; Farhar and Houston, 1996). This review of US national surveys indicated between fifty six percent and eighty percent of respondents would pay a premium for environmental protection or renewable electricity (Farhar, 1996). However, the trends identified in these reports (Farhar, 1993; Farhar, 1996; Farhar and Houston, 1996) were based on results from samples which used different sampling methods, and grouped together responses from questions of different wording. The reports dealt with descriptives only, and did not attempt any cross tabulation of results, even in original survey work (Farhar and Coburn, 1999). This led to the over-generalisation of results and implied that the results represented the willingness to pay of a wider population than the population sampled.

Farhar also completed a survey of utility market research (Farhar, 1999), which indicated a general willingness to pay for renewables and showed a relationship between the number willing to pay and the premium level. Using data from twelve US utility surveys, Farhar (1999) constructed an aggregated willingness to pay curve with the equation:

$$Y = 100e^{(-0.104)M} \tag{3-1}$$

where M was the dollar monthly premium and Y was the cumulative percentage of respondents. In deriving the least squares fit to the data, the square of the correlation coefficient was $R^2 = 0.76$, which indicated that seventy six percent of the data could be explained by using this formula (hence the derived equation was a relatively good fit to the data). This curve is shown, along with the original data points from the twelve surveys, in Figure 3-1. The Y axis intercept was set at one hundred percent based on the assumption that all respondents may have, if asked, been willing to pay some amount between zero and the smallest premium unit ($1 in this case).

The generalisation of data in this report (Farhar, 1999) was based on poor assumptions of equity in sample populations, questionnaire administration and wording of the willingness to pay question.

It was generally more difficult to assess the quality of local market research by supply companies, since the results were generally considered commercially sensitive and were not readily available (Farhar and Houston, 1996; Holt, 1997a). However, significant differences in stated willingness to pay were found when comparing utility regional and national results (Farhar, 1996; Farhar and Houston, 1996).

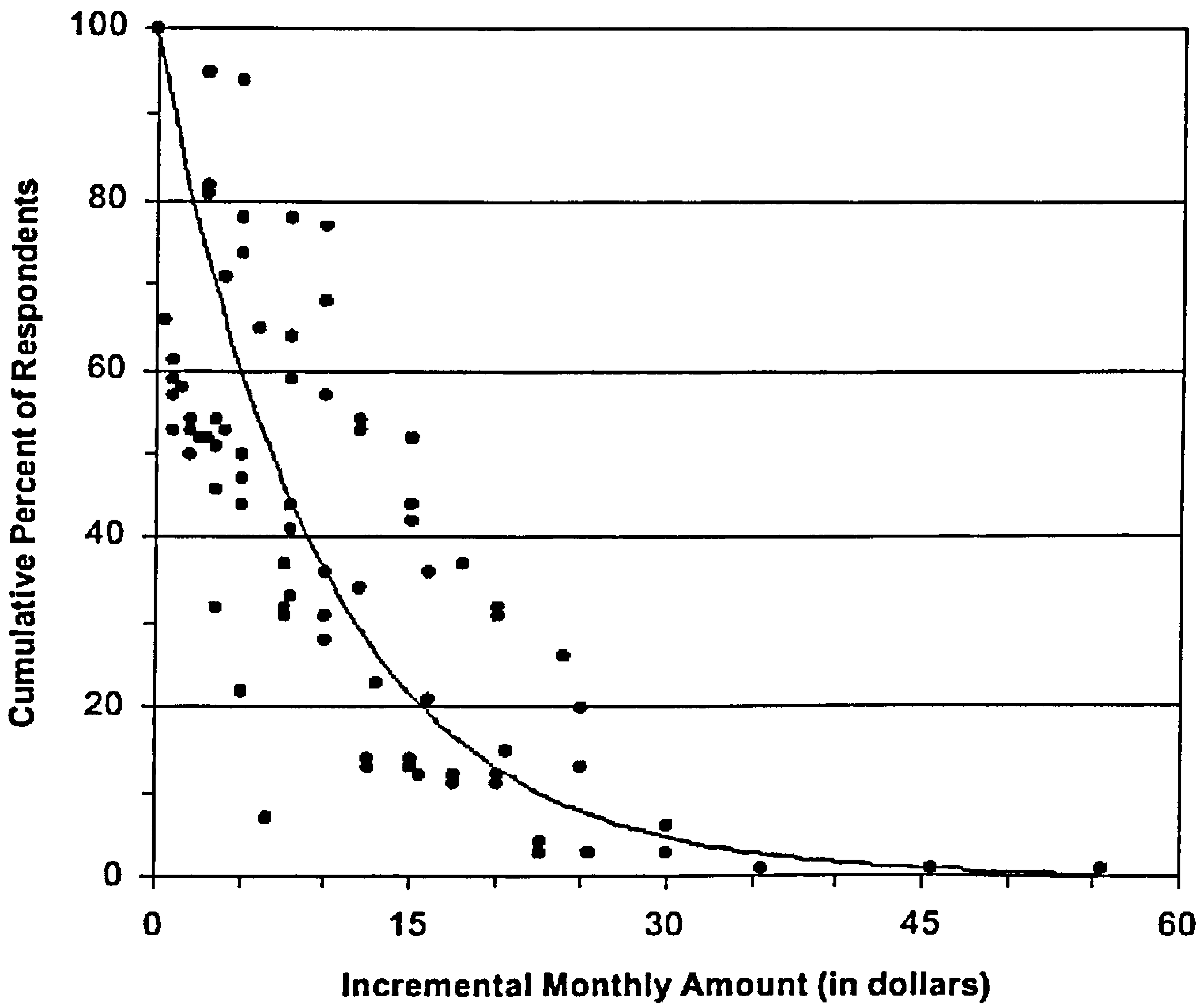

Figure 3-1. Aggregated willingness to pay curve for residential customers (Farhar, 1999)

Farhar did recognise the difficulties of summarising utility market research in "Energy and the environment: the public view" (Farhar, 1996), where she noted there was a lack of clarity of sampling procedures and poor reporting of the question wording in reports of utility market research.

Whilst Farhar's research has been cited as the primary source of survey results on willingness to pay (Holt, 1997a; Swezey, Houston and Porter, 1998; Wiser and Pickle, 1998; Lamarre, 1997; Byrnes, Rahimzadeh, Baugh and Jones, 1995; Wiser, 1998), none of this review work had investigated the reasons behind variation in willingness to pay.

A survey by Rose, Clark, Poe, Rondeau and Schulze (1997; 2002) did investigate willingness to pay (for a specific utility product) and some demographic variables (age, gender and education). The authors found that age was negatively correlated with participation in the proposed green tariff scheme and that male gender showed a strong positive correlation with participation.

In a review of research on environmental attitudes, Kempton (1993) concluded that the only socio-demographic variable which strongly and consistently correlated with public environmentalism was age, with younger age groups generally holding stronger environmental values.

This dearth of investigation into the demographic variables which could underlie willingness to pay for renewable electricity prompted several research hypotheses which were tested using the questionnaire.

Prior to the administration of the final questionnaire, a study was published by Byrnes, Jones and Goodman (1999) which investigated willingness to pay and socio-demographic explanatory variables. Results indicated that the following variables were linked to willingness to pay: education, age, whether the respondent owned their own home, whether the respondent contributed to nature and wildlife protection organisations, whether the respondent's household comprised a family with children, and response to several attitude statements (objection to potential free-riders, utility profit from developing renewable energy, future fall in cost of electricity from renewables, importance of jobs relative to environmental regulations, individual responsibility for energy conservation, private development of renewable energy programs preferable to government action). Income was not found to be significantly related to willingness to pay. The authors utilised telephone and mail surveys, and market simulations. Seventy three percent of respondents expressed a willingness to support utility investment in renewable energy programs but only thirteen percent registered to participate in them through market simulations. The differences in willingness to pay across hypothetical and actual payment conditions were hypothesised to be due to free-riding, respondent uncertainty and differences in the way respondents processed information under the two conditions. These research findings were not able to influence the final wording of the piloted questionnaire, but it, and later publications, were able to influence the analysis of results.

After the questionnaire had been administered, several relevant research publications came into the public domain. One was by Ferguson (1999), who reviewed several utility market research programs in the Northwest US which incorporated demographic variables. Results indicated a relationship between willingness to pay for renewables and demographic variables such as age, gender, income, social group and education. Willingness to pay was also related to awareness of renewables and attitudes towards conservation support in general. Ferguson (1999) reported summary data from several utility surveys, with little comment on the method of sampling or questioning, and there was little comment on the applicability of these findings beyond the survey sample. However, Ferguson (1999) did recognise difficulties in comparisons between surveys due to the way in which questions were worded and presented.

Roe, Teisl, Levy and Russell (2001) considered willingness to pay more for reduced emissions, reduced emissions with increased use of renewable energy, and reduced emissions with increased use of nuclear energy as consumer options for electricity supply. They compared willingness to pay with the socio-demographic variables location (regions of the US), income, education and affiliation with environmental organisation. Whilst the authors did not comment in detail on the statistical significance of variations in willingness to pay with these socio-demographic variables, the results did indicate that those in the northeast and northwest US were willing to pay a higher average premium, and that the average premium respondents were willing to pay was higher for higher income respondents, for a product with reduced emissions and increased use of renewable energy.

In reviewing actual participation rates in green tariff schemes, Wiser, Bolinger and Holt (2000) found that participation generally declined as premium increased, although this was not true for the low premium range of $1 to $10. The participation generally increased over time, although some schemes were able to achieve higher levels of participation in the first year. The size of the utility also appeared to be a factor affecting participation, with smaller utilities outperforming larger utilities. Wiser, Bolinger and Holt (2000) suggested that participation was most significantly affected by the quality of the product, how well it was marketed, the credibility of the utility and the ease of participation. However, the authors presented very little statistical evidence to justify these conclusions. Wiser, Bolinger and Holt (2000) also suggested that slow uptake of green tariff products could be explained by the prohibitive costs to marketers of attracting, signing up and retaining customers, and by the regulatory rules which limited the potential cost savings to switchers.

In summary, US investigations into willingness to pay for electricity from renewable sources has shown significant proportions of the population willing to pay a premium. Age, gender, attitude, income, social group, awareness of renewable energy and location have all shown a relationship with willingness to pay or premium level in US surveys.

3.4 Willingness to pay experience from the UK

In comparison with the US, relatively little market research had been done on willingness to pay for renewable electricity in the UK. Research into environmental purchasing, socio-demographic variables and environmental attitudes was, however, useful in determining the possible factors involved in willingness to pay for renewable electricity.

3.4.1 Environmental attitudes

In the 2001 UK survey of public attitudes to quality of life and to the environment (Department for Environment, Food and Rural Affairs, 2002), one in four people mentioned the environment as an issue for government to address, but only twenty-five percent of respondents thought that the use of gas and electricity in the home contributed to climate change. Two in five respondents reported that they regularly cut down on use of electricity and gas, but the majority did this to save money and only fifteen percent reported that they did this to help the environment or reduce pollution. Responses were presented by age, gender, education, social class and Government Office region, but no statistical analysis of attitudinal and socio-demographic variables was presented. This same survey questioned buying actions such as the use of low energy light bulbs in the home and purchasing of organic foods, and whilst raw data indicated use of low energy light bulbs varied significantly with education, the report suggested that higher age groups and higher social class corresponded to higher proportions of respondents who had used low-energy light bulbs in the last twelve months. Ninety percent of respondents supported the policy of increasing the use of renewable energy sources.

General environmental concern had been a consistent finding in UK surveys. Eighty percent of respondents were very concerned or quite concerned about the environment in 1995, with ninety percent of people in A category occupations concerned compared with sixty six percent of people in D and E categories (National Consumer Council, 1997). This same report summarised a 1996 survey where ninety percent of a 1,960 sample were very or fairly concerned about pollution, conservation and the environment, with no significant difference in the level of concern shown across income groups and political affiliations. Worcester (1996) reported for MORI that twelve percent of the British adult population could be considered "deep green", having agreed with a survey statement "we should protect the environment at all costs, regardless of economic consideration". This survey, in 1996, indicated that there was a larger proportion of "deep greens" amongst older people, and working-class households contained a higher proportion of "deep greens" compared with middle-class households.

A study of environmental purchasing showed that purchasing behaviour would not alter until people were confident that their purchasing decisions could help the environment, and that people were strongly concerned about the lack of environmental information about products (Research International, 1996).

Therefore, attitudinal surveys and environmental purchasing surveys in the UK generally showed a significant concern for environmental issues, and a large proportion of respondents were buying products of a better environmental performance, but limited analysis had been done to link these results to socio-demographic variables such as age, gender, education, social class, income and political affiliation.

3.4.2 Willingness to pay surveys

Three surveys were available which directly questioned respondents' willingness to pay for renewable electricity, of which one was in the non-domestic sector (Ecotec, 1996) and two were in the domestic sector (Parliamentary Renewable and Sustainable Energy Group, 1996; Colbourne, Lorenzoni, Powell and Fleming, 1999).

The report by Ecotec (1996) showed that twenty two percent of respondents were "quite interested" or "very interested" in a scheme to voluntarily pay more for green electricity. The same survey showed that a universal premium on all customers was preferred, with fifty four percent of respondents "quite interested" or "very interested". The respondents favouring a voluntary scheme had an average stated premium of 5.8 percent, while those favouring the obligatory scheme had an average premium of 6.2 percent (no standard deviation was given). The cumulative willingness to pay was derived from results and is shown in Figure 3-2. This survey was based on 104 responses (approximately a five percent response rate) from a target group covering a range of economic sectors and organisational size. No investigation of willingness to pay and independent variables was recorded.

In 1996 MORI completed a survey for the Parliamentary Renewable and Sustainable Energy Group (1996) which questioned willingness to pay. Twenty one percent of respondents were willing to pay more for renewables, with a cumulative willingness to pay derived from results which is shown in Figure 3-3. The average premium respondents were willing to pay was sixteen percent (no standard deviation was given).

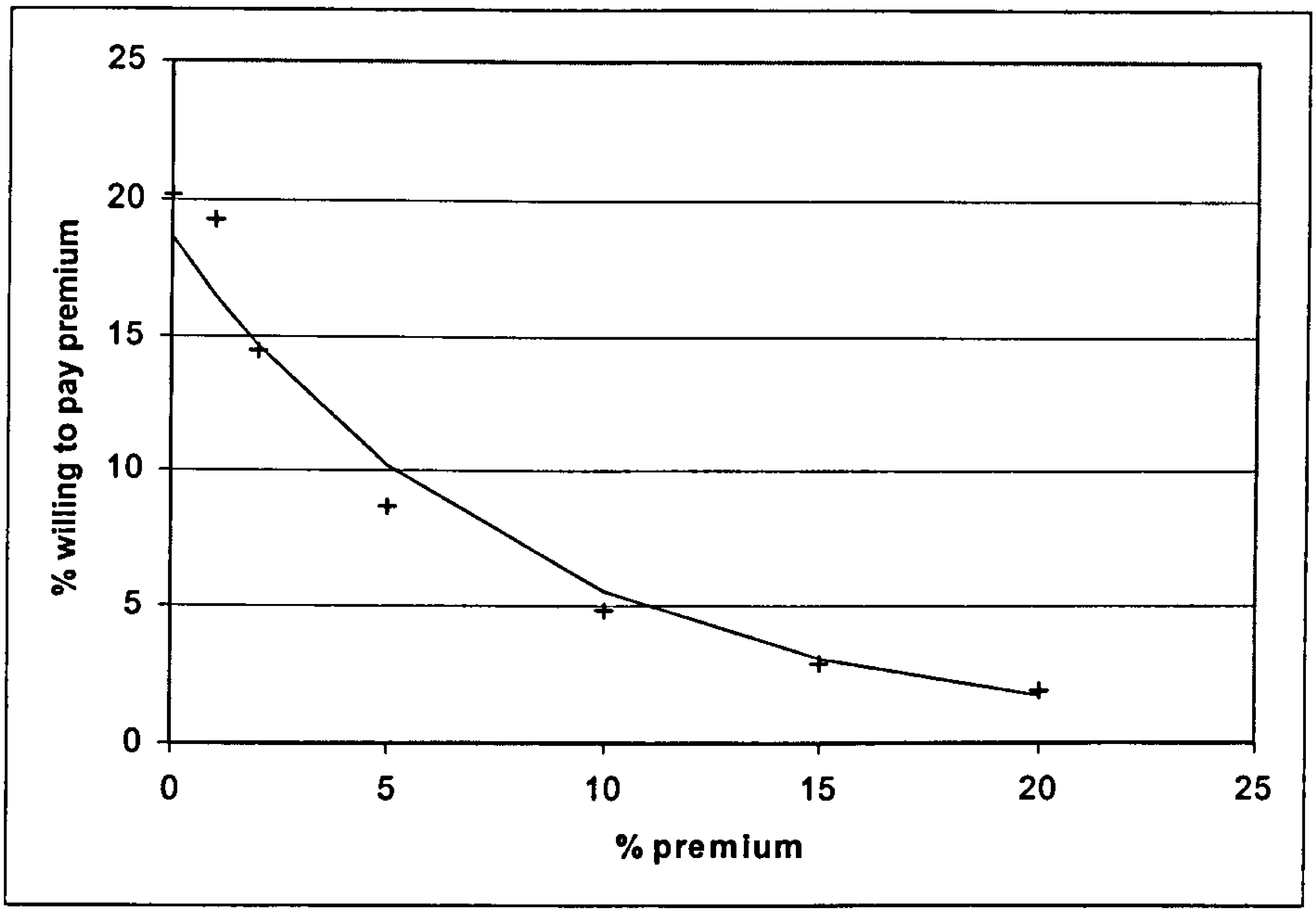

Figure 3-2. Ecotec survey results (non-domestic sector)

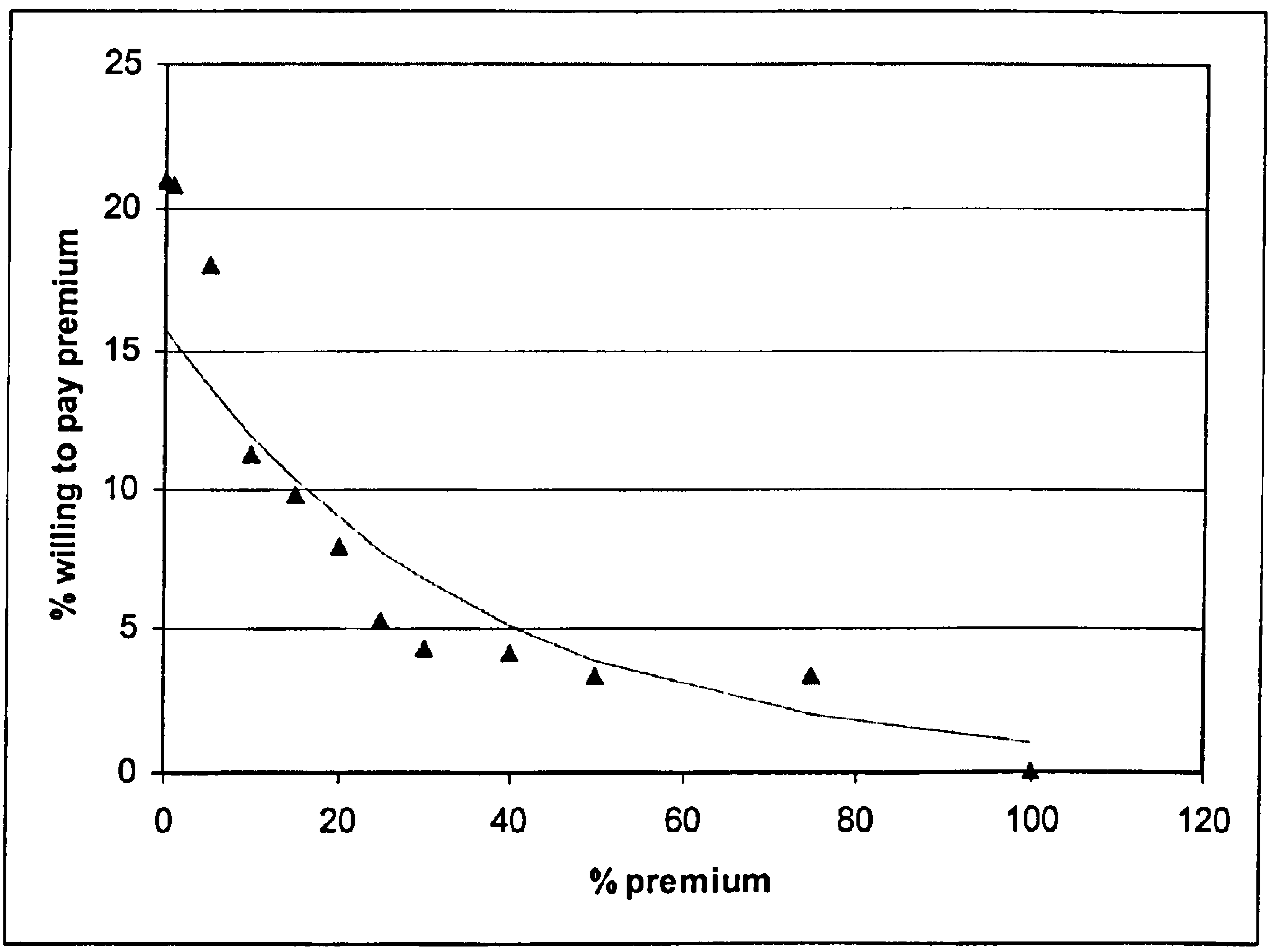

Figure 3-3. MORI opinion poll results for PRASEG

Colbourne, Lorenzoni, Powell and Fleming (1999) administered a survey to Leicester households. This survey was designed to investigate attitudinal responses to engineering solutions for urban energy planning. The survey was administered to a stratified random sample of the Leicester population (742 completed questionnaires, a response rate of 27.2 percent), and included a question on willingness to pay. Colbourne, Lorenzoni, Powell and Fleming (1999) found that thirty four percent of respondents were willing to pay for renewable electricity, and the average premium people were willing to pay was 16.6 percent (no standard deviation given). The cumulative frequency response for this survey was derived from results and is shown in Figure 3-4.

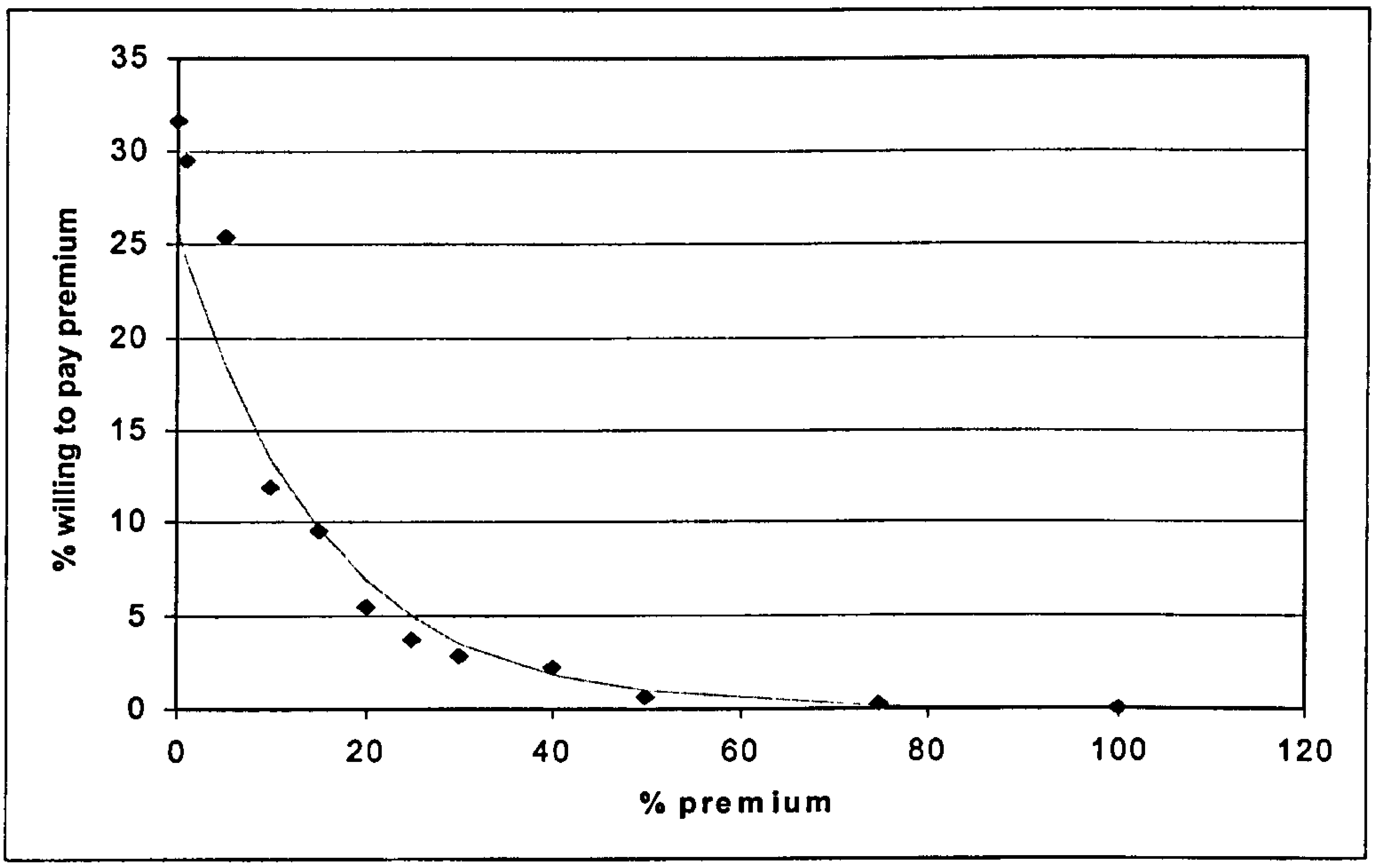

Figure 3-4. Colbourne, Lorenzoni, Powell and Fleming survey results

Results of this research indicated that a large number of respondents (eighty one percent) would be willing to consider buying an energy-efficient appliance compared with a standard model, and that this was correlated to previous energy-related experience (a confirmation of Ferguson's (1999) findings). Results of the willingness to pay for renewable electricity question was significantly correlated with income ($r=0.236$, $N=551$, $p=0.001$), but no relationship was found between the level of premium respondents were willing to pay and income (χ^2=4.001, N=179, ν=6, p=0.676). The authors carried out several tests to determine the relationship between willingness to pay and individual independent variables, and between premium and individual independent variables, but no multiple regression was completed. They also compared results with the national survey by MORI (Parliamentary Renewable and Sustainable Energy Group, 1996) and found a significant difference (Z=6.456, p<0.001) in the proportions willing to pay more for renewable electricity.

Although several utilities were offering green power products in the UK market, utility market research was not publicly available due to commercial sensitivity. All UK electricity suppliers were contacted at an early stage of this investigation to determine whether they had carried out any market research on green tariffs. One utility which was willing to provide survey information for this investigation had shown that fifty four percent of respondents in a focus group survey were willing to pay a premium for renewable electricity, with an average premium of 4.7 percent (Haley, 1998). The same utility surveyed its business customers and found sixty five percent interested in green supply, forty five to fifty percent interested in green funds, forty percent not willing to pay any premium, and a premium range of 1.75 percent to four percent. These willingness to pay results were not related to any independent variables.

Therefore, UK market research had shown that environmental purchasing behaviour was related to attitude (Worcester, 1996; Research International, 1996), age (Department for Environment, Food and Rural Affairs, 2002; Worcester, 1996), and social class (Department for Environment, Food and Rural Affairs, 2002; Worcester, 1996). Findings of surveys of willingness to pay for renewable electricity found that willingness to pay and premium correlated with location (Colbourne, Lorenzoni, Powell and Fleming, 1999), energy related experience (Colbourne, Lorenzoni, Powell and Fleming, 1999) and income (Colbourne, Lorenzoni, Powell and Fleming, 1999).

3.5 The concept of a willingness to pay survey

In developing a willingness to pay survey, the initial hypotheses for investigation were: that willingness to pay for electricity generated from renewable sources was related to attitude, that willingness to pay was related to social class, that willingness to pay was different at a local level compared to a national level, and that willingness to pay varied with the level of premium required. These hypotheses were based on willingness to pay research in the US (Farhar, 1993; Farhar and Houston, 1996; Farhar, 1996; Lutzenhiser, 1993) and UK research into consumer attitudes and green purchasing (Worcester, 1996; Colbourne, 1998; Colbourne, Lorenzoni, Powell and Fleming, 1999).

As the questionnaire developed beyond the pilot stage, and further research was published which linked willingness to pay for electricity from renewable sources with demographic variables, the hypotheses were expanded to include: willingness to pay for electricity generated from renewable sources was related to age, willingness to pay was related to income, willingness to pay was related to gender, and willingness to pay was related to awareness of energy issues. These hypotheses were based on willingness to pay research in the US (Rose, Clark, Poe, Rondeau and Schulze, 1997; Byrnes, Jones and Goodman, 1999; Ferguson, 1999).

There were therefore eight hypotheses:

- H1: willingness to pay for electricity from renewable sources was related to attitude.
- H2: willingness to pay for electricity from renewable sources was related to social class.
- H3: willingness to pay for electricity from renewable sources was related to location (national results different to localised results).
- H4: willingness to pay for electricity from renewable sources was related to premium.

- H5: willingness to pay for electricity from renewable sources was related to age.
- H6: willingness to pay for electricity from renewable sources was related to income.
- H7: willingness to pay for electricity from renewable sources was related to gender.
- H8: willingness to pay for electricity from renewable sources was related to awareness of energy issues.

3.6 The method used in developing and administering a willingness to pay survey

In order to investigate willingness to pay for renewable energy, a questionnaire was devised and administered within the case study area of Leicester City.

Willingness to pay surveys had already been carried out for a national representative sample of adults by MORI (Parliamentary Renewable and Sustainable Energy Group, 1996). An energy efficiency questionnaire had already been carried out for a random sample of Leicester's population, which included a willingness to pay for renewables question (Colbourne, 1998).

In order to avoid replication of existing willingness to pay results, the target population of this survey was a sub section of the residents of Leicester: those who had contacted the energy efficiency advice centre for advice.

The results of the survey could then be compared with surveys of representative samples of the national population and Leicester's population. Comparison was further facilitated by deliberately wording the question on willingness to pay to be as similar as possible to the two other surveys. This would enable the testing of the second hypothesis, that willingness to pay was different at a local level compared to a national level. It would also test the final hypothesis, that willingness to pay was related to awareness of energy issues. This awareness was assumed due to the contact which the sample had previously had with the Energy Efficiency Advice Centre (all of the sample population were on the database held by the Energy Efficiency Advice Centre as a result of having received advice from them in the past), although no measure of the level of awareness was estimated.

3.6.1 The first pilot survey

In order to develop a suitable questionnaire, an initial pilot phase was initiated. The pilot questionnaire was designed in late April 1998. The questionnaire was administered by officers of Leicester City Council, either during home energy surveys or by post, following initial contact with the City Council by each subject.

Use of the questionnaire during home surveys or through postal contact was initiated on 13th May 1998 and terminated on 20th July 1998. During this two month period a total of seventy seven home surveys and fifty seven postal surveys were undertaken by the Housing Department, which were accompanied by the questionnaires. The pilot received forty six completed questionnaires from home surveys and ten completed questionnaires from postal surveys, a response rate of sixty percent and eighteen percent respectively. Based on a total questionnaire return for fifty six subjects, preliminary analysis of the pilot questionnaire was completed.

The sample for the pilot comprised citizens of Leicester who had contacted the Housing Department of Leicester City Council for energy efficiency advice. The variation in the method of administering the questionnaire introduced a confounding variable, that of the influence of the experimenter E during the administration of the questionnaire. Whilst the results of the pilot questionnaires may therefore be invalid due to the inability to standardise the administration procedure during the pilot, the process of piloting the questionnaire remained an important and valid process in highlighting the difficulties of language and layout in the questionnaire. The qualitative feedback from the small number of home surveyors (as experimenters) administering the questionnaire also proved valuable for such purposes.

The questionnaire contained a question regarding willingness to pay, and eight attitudinal questions. The attitudinal questions took the format of rating scale items (statements) with five possible responses for each item. This is known as a Likert scale.

The statements related to energy-related environmental issues. They were:

- I would be willing to switch electricity company if I was offered “green” electricity;
- I have no preference as to the source of my electricity;
- I think individuals should be responsible for investment in “green” electricity;
- I am concerned about climate change;
- I don’t think the way we make electricity causes air pollution;
- “Green” power should be supplied at no extra cost;
- I would be willing to switch supplier to get cheaper electricity;
- The Government should not be responsible for taking action to increase the amount of “green” electricity available.

The five possible responses were: strongly agree, slightly agree, neutral, slightly disagree, strongly disagree.

The statements were worded to mix positive and negative statements, such that someone with strong environmental beliefs would not be completing the same response for each item. The statements were also worded to cover three specific topics: general concern for environmental issues, feelings of individual social responsibility, and attitude towards the specific behaviour of purchasing a green electricity tariff. The order of the statements mixed these three categories together.

This was followed by an open response item which directly questioned the willingness to pay for renewable electricity. The subject (S) was asked to express their willingness to pay as a pound value, over and above their assumed quarterly electricity bill of £100, which they would be willing to pay in order to join a green tariff scheme providing one hundred percent of electricity demand from renewable sources.

Results of the preliminary analysis into the pilot questionnaire indicated that:

- Likert scale items "I don't think the way we make electricity causes air pollution" and "I have no preference as to the source of my electricity" needed to be reworded, since the facility index for these items was low; and

- the direct question on willingness to pay for green electricity needed to be reworded to lower the assumed level of the electricity bill (based on comments from respondents). It also needed to be emphasised in importance, to attempt to resolve the low response rate (fourteen non responses, twenty five percent non response rate).

Preliminary analysis of the results indicated a general level of support for environmental issues and renewable electricity in general, but the vast majority of respondents felt that they would not be willing to pay more for renewable energy and would prefer to switch supplier for cheaper electricity. However, the thirty five percent which indicated they would be willing to pay more for renewable electricity (ignoring non responses) still represented a significant portion of the market, with a relatively high average premium (18.86 percent, standard deviation 8.89 percent, excluding zero responses, 6.29 percent average, 12.57 percent standard deviation, including zero responses, and average 4.71 percent, standard deviation 11.22 percent, including non responses as assumed zero responses). The cumulative willingness to pay of this sub section population is shown in Figure 3-5.

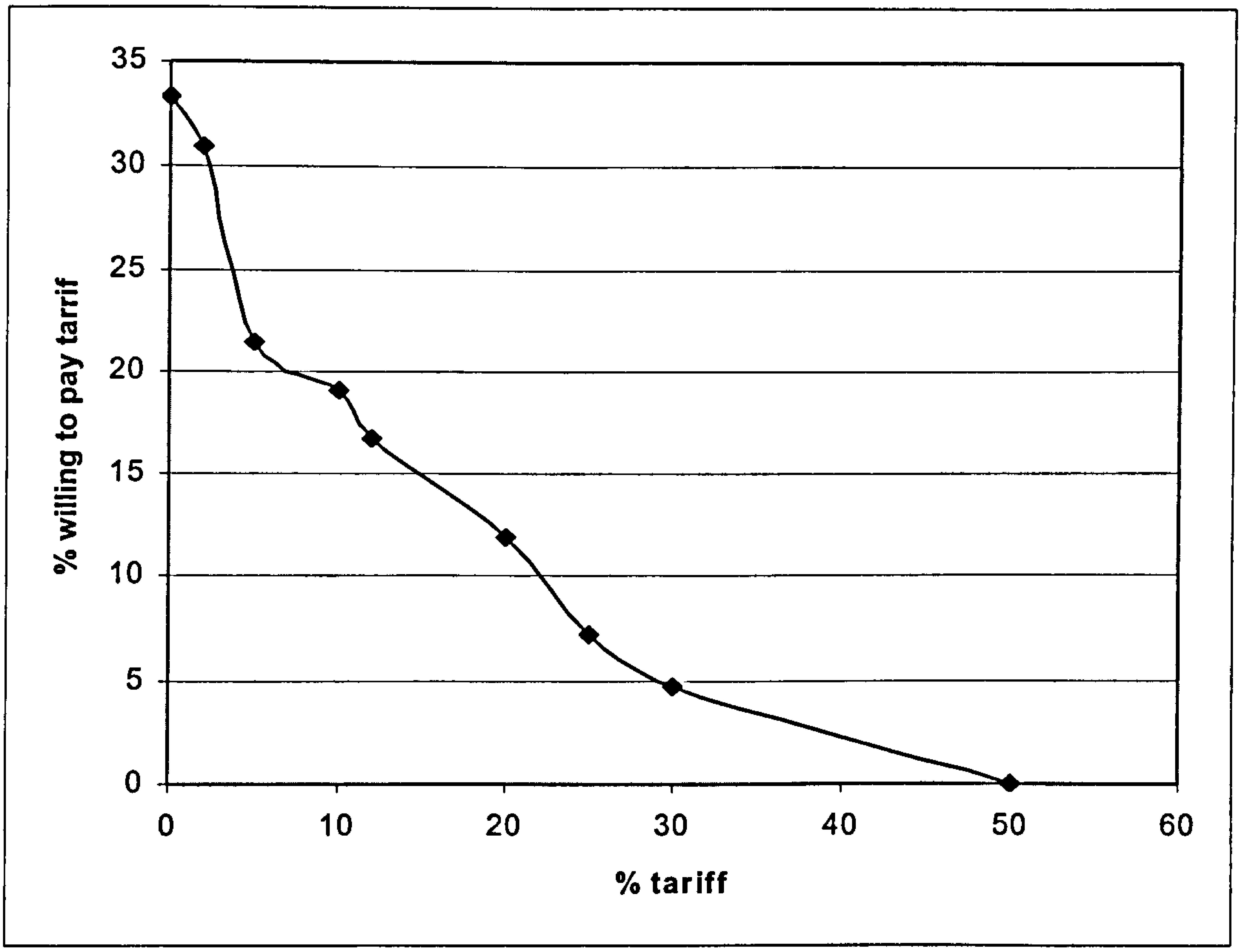

Figure 3-5. The cumulative willingness to pay results for pilot one (excluding zero responses)

3.6.2 The second pilot survey

Upon completion of the first pilot stage and improvement of the questionnaire, the opportunity arose to incorporate the questions into a much larger survey of energy efficiency, to be administered by Leicester City Council. This enabled access to a large database of residents of Leicester, and reduced the costs of administration of the survey.

In order to complete a pilot of the entire questionnaire, this questionnaire was mailed to a random sample of Leicester citizens in the LE1 area of the city, who had contacted the Leicester Energy Efficiency Advice Centre. 447 questionnaires were mailed to a random selection of households on 23rd October 1998, with thirty one returns by 11th January 1999 (a response rate of 6.9 percent). Mailing of the questionnaires resulted in the removal of the experimenter as an influence on the subject.

The questionnaire for the second pilot incorporated the eight attitudinal statements, which had been adjusted following the results of the first pilot. The willingness to pay question was also included. It had been altered to comprise of two parts: the first part asked whether the respondent would be willing to pay more for electricity from renewable sources and the second part asked the respondent to express their willingness to pay as a pound value, over and above their assumed yearly electricity bill of £100, which they would be willing to pay in order to join a green tariff scheme providing one hundred percent of electricity demand from renewable sources.

Results of the preliminary analysis into the second pilot questionnaire indicated that:

- the Likert scale item "I think the way we make electricity causes air pollution" needed to be reworded, since Spearman's Rho was low. It was altered to its original wording, since no further piloting was possible in order to test further versions of the item.

Results from the willingness to pay question showed a similar average level of premium as the first pilot questionnaire (15.91 percent (excluding zero responses), standard deviation 11.01 percent, results are displayed as cumulative willingness to pay in Figure 3-6, including zero responses average was 14.58 percent, standard deviation 11.58 percent, including non responses as zero responses average was 11.67 percent, standard deviation 11.13 percent).

The addition of a section to the willingness to pay question allowed easier analysis of the results, and reduced the number of non responses to three (a ten percent non-response rate, compared with twenty five percent non-response rate for pilot one). The second pilot had a higher proportion willing to pay more, at forty three percent of respondents (compared with thirty five percent for the first pilot, ignoring non responses). It was not possible to determine whether the differences in pilot one and two for these questions were statistically significant due to the small sample sizes.

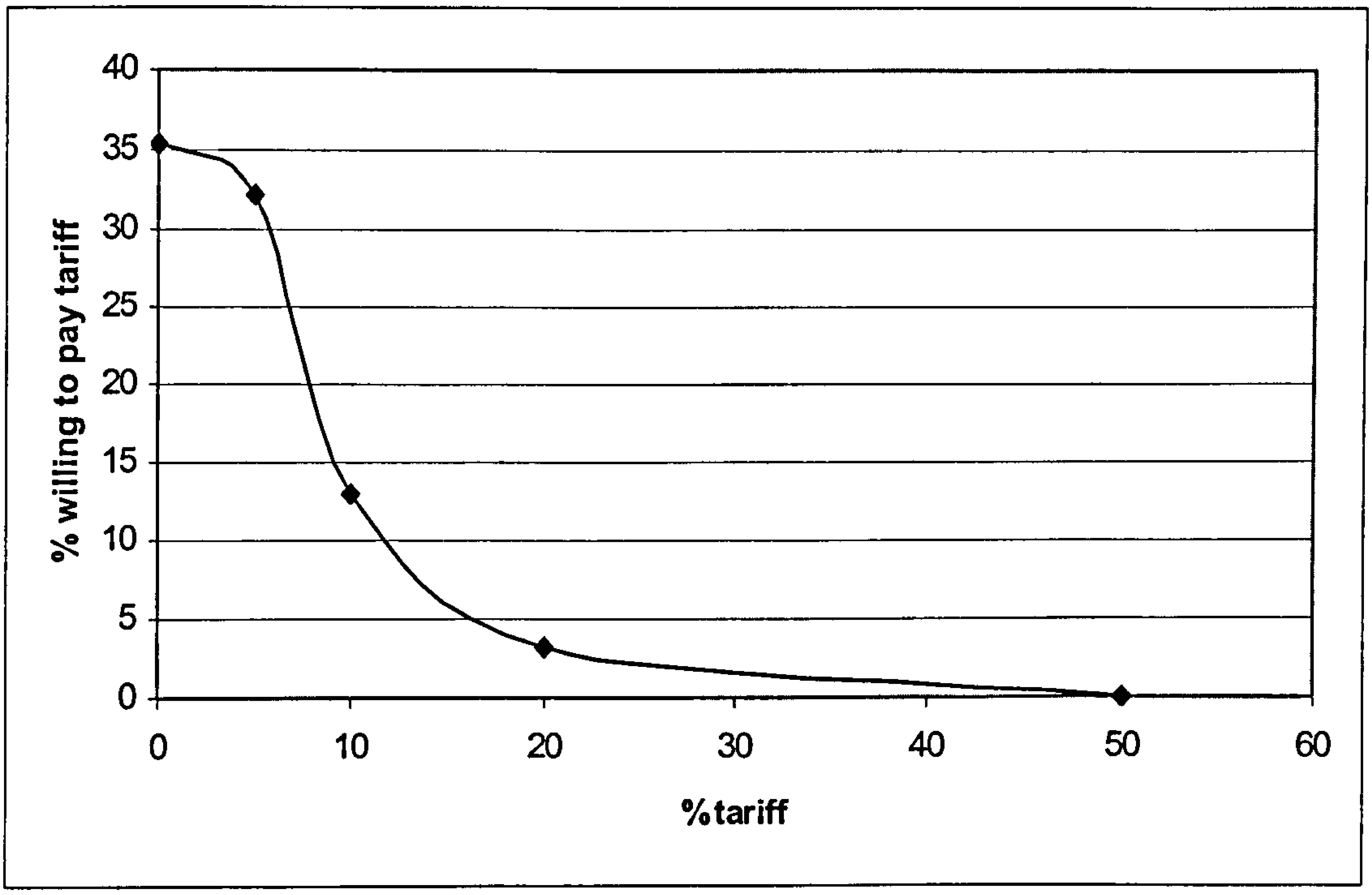

Figure 3-6. The cumulative willingness to pay results for pilot two (excluding zero responses)

3.6.3 Administration of the final survey

The full scale mailing of the questionnaire was initiated in March 1999, with a prize draw for responses received before 31st April 1999. A copy of the questionnaire is contained within Appendix I. Every contact on the Energy Efficiency Advice Centre database was mailed a questionnaire: a total of 8,700. By the prize draw closing date, a total of 692 responses had been received. A further 54 were received soon after the closing date, and were included in the analysis. This equated to a response rate of 8.57 percent. Responses were analysed using SPSS (Statistical Package for Social Scientists), with over 100 variables identified from each respondent in the full questionnaire.

Before and after administration of the questionnaire, publications (Byrnes, Jones and Goodman, 1999; Ferguson, 1999; Roe, Teisl, Levy and Russell, 2001; Wiser, Bolinger and Holt, 2000) indicated that analysis of willingness to pay and socio-demographic variables showed a relationship between the two. Whilst this research was not published in time to influence the final wording of the questionnaire, it did influence the analysis. Leicester City Council, in designing the majority of the questionnaire, had incorporated questions which were of interest for investigation, including age, income, whether the respondent had visited the Energy Efficiency Advice Centre, the Ark or the Ecohouse (these three places were all Leicester-based environmental information centres: the Ecohouse was an environmental demonstration home, the Ark was an environmental shop and cafe, and the Energy Efficiency Advice Centre was a Government funded advice centre selling low energy items). Due to the poor design of the age question it was only possible to identify two age groups of respondents, adult or pensioner (Leicester City Council had designed the questionnaire such that they could identify those who qualified for grant aid as pensioners). In addition, address details of respondents enabled the identification of gender and social class.

The social group of the respondent was identified from their postcode using GB Profiler '91 (a software database). Social grouping was based on 85 factors (including income) identified from 1991 Census data, and did not rely on self reporting (and was therefore less intrusive to the respondent (Blake and Openshaw, 1994)), unlike the question which related to the income bracket of the respondent. It was hypothesised that social grouping would exhibit a stronger relationship with willingness to pay than income alone. Income was hypothesised to be subject to bias, as it did not reflect spending patterns in terms of disposable income and lifestyle choices.

The final wording of the attitudinal statements is shown in Table 3-1, and the coding of responses is also shown. The statements were worded to mix positive and negative statements, such that someone with strong environmental beliefs would not be completing the same response for each item. Coding was arranged such that the response which would generally be considered pro-environmental was given the higher coding value.

Table 3-1. Attitudinal statement wording and response coding for the final questionnaire

Statement	**Response coding**				
	Strongly agree	Slightly agree	Neutral	Slightly disagree	Strongly disagree
I am not concerned about climate change	1	2	3	4	5
I would be willing to change electricity company if I was offered "green" electricity	5	4	3	2	1
I think the way we make electricity causes air pollution	5	4	3	2	1
I think individuals should be responsible for investment in "green" electricity	5	4	3	2	1
"Green" power should be supplied at no extra cost	5	4	3	2	1
The government should not be responsible for action to increase the amount of "green" electricity	1	2	3	4	5
I have no preference as to how my electricity is made	1	2	3	4	5
I would not change electricity company just for cheaper electricity	5	4	3	2	1

3.7 Results of the willingness to pay survey

3.7.1 Basic descriptives

35.85 percent of the sample indicated they were willing to pay more for renewable electricity. Based on the sample proportion willing to pay it was possible to estimate the population proportion willing to pay. The proportion of the population willing to pay more for renewable electricity was 35.85 +/- 3.59 percent (N=636, α=0.05 with finite population correction). In this investigation, the population referred to were those who had contacted the Energy Efficiency Advice Centre in Leicester. The formula used for this calculation is contained within Appendix I Section I.4.

The mean premium respondents were willing to pay was 19.11 percent (standard deviation 18.74 percent), and again it was possible to estimate the mean premium for the population using the sample results. The mean premium which the whole population was willing to pay for renewable electricity was 19.11 +/- 2.48 percent (N=219, α=0.05). See Figure 3-7 and Table 3-2 for more information. Cumulative willingness to pay is shown in Figure 3-8.

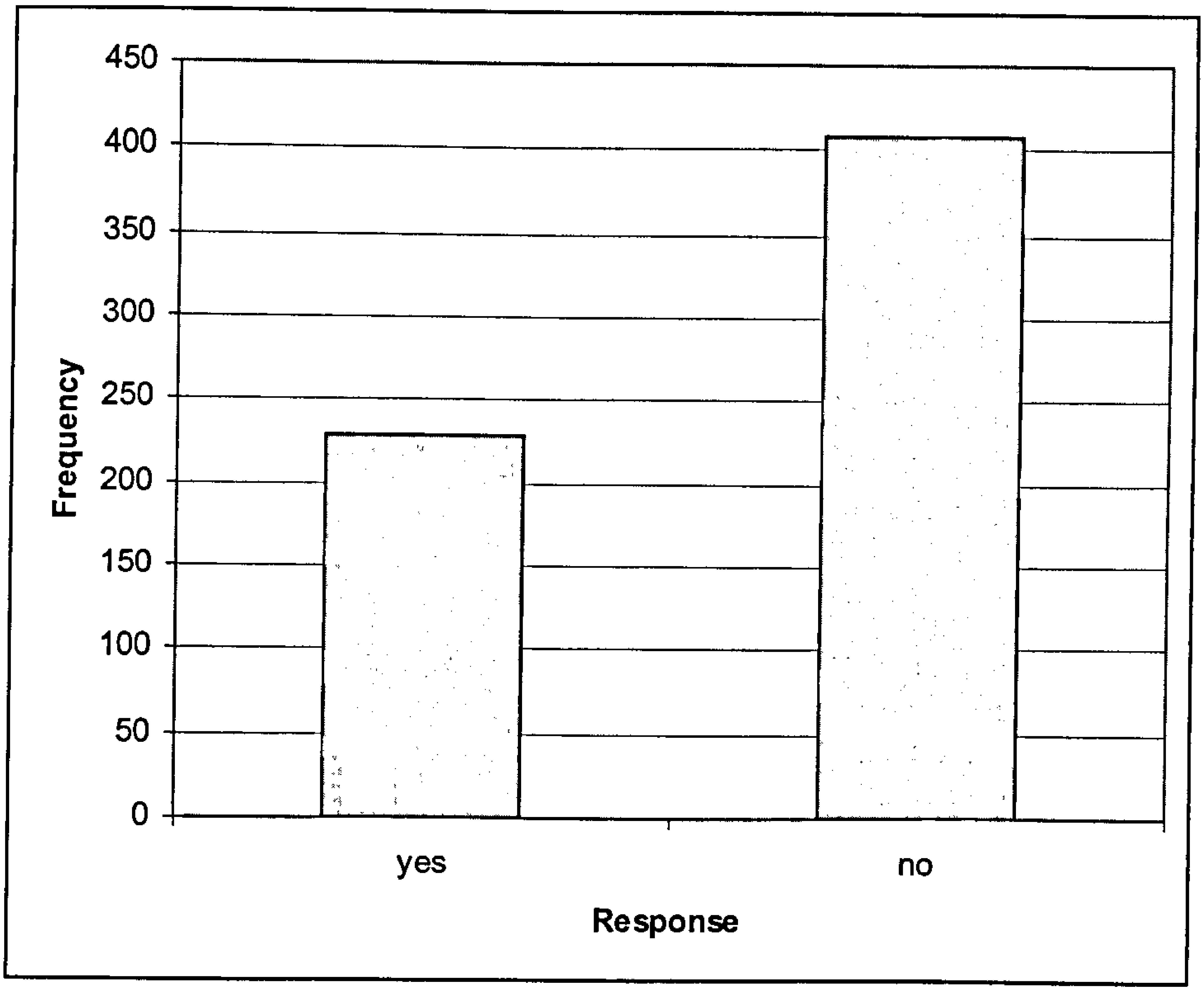

Figure 3-7. "Would you be willing to pay more for renewable electricity?" (N=636)

Table 3-2. "Imagine that your yearly electricity bill is £100. How much EXTRA would you be willing to pay to get ALL of your electricity from renewable sources?" (N=219)

Response	**Frequency**	**Percentage of responses**
0	18	8.2
2	1	0.5
5	25	11.4
10	71	32.4
12	1	0.5
15	10	4.6
18	1	0.5
19	1	0.5
20	38	17.4
25	13	5.9
30	8	3.7
33	1	0.5
40	1	0.5
50	25	11.4
100	5	2.3
TOTAL	219	100
Missing	9	
TOTAL	228	

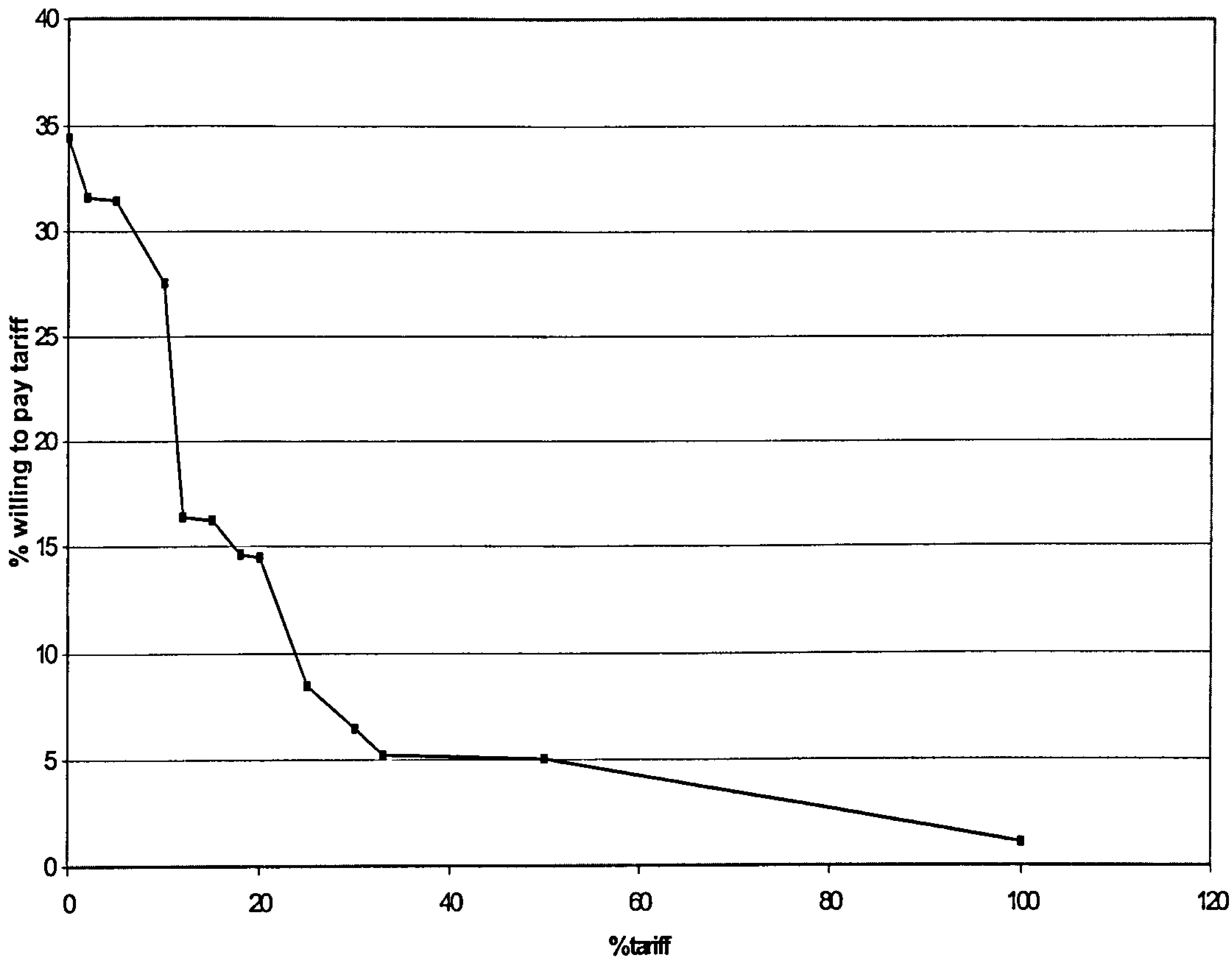

Figure 3-8. The cumulative willingness to pay results for the full scale questionnaire

Many factors might influence an individual's response to these questions. The primary variables of interest in this investigation were social group, income and attitude. The nature of the questionnaire also allowed some analysis of gender, age and whether the respondent had have visited environmental information centres in Leicester. Raw data for these variables is contained within Appendix I.

3.7.2 Factor analysis of attitudinal statements

Factor analysis is a data reduction technique. It was used to combine attitudinal statements which respondents viewed as being similar. This would then simplify further analysis of the relationship between attitude and willingness to pay or premium.

There were eight attitudinal statements in the questionnaire. The attitudinal statements were worded such that two statements related to concern for global environmental issues, two statements related to responsibility for renewables investment, and four statements related to attitude towards the behaviour (which involved changing supplier to receive a higher priced green tariff).

It was hypothesised that significant correlation would be found between statements which related to similar issues. It was therefore expected that factor analysis would lead to the development of three factors, relating to the environment, responsibility and behaviour.

Factor analysis on the eight attitudinal statements indicated that a total variance of 59.8 percent in all eight variables could be explained by three factors. The pattern matrix shown in Table 3-3 was obtained using an oblimin rotation in SPSS (the purpose of rotation is to simplify the pattern matrix so that factors can be identified, and oblique rotation using the oblimin function allows for some correlation between factors to exist). However, the three factors identified were not as expected.

Table 3-3. Pattern matrix for oblimin rotation with factor analysis

	Factor 1	Factor 2	Factor 3
I am not concerned about climate change	0.822		
I would be willing to change electricity company if I was offered "green" electricity	0.776		0.303
I think the way we make electricity causes air pollution	0.622	-0.340	
I think individuals should be responsible for investment in "green" electricity	0.379		-0.316
"Green" power should be supplied at no extra cost		-0.694	
The government should not be responsible for action to increase the amount of "green" electricity	0.572	0.628	
I have no preference as to how my electricity is made		0.544	
I would not change electricity company just for cheaper electricity			0.926

The figures shown in Table 3-3 are open to interpretation. The factor loadings vary from zero (no association) to plus or minus one (perfect association). High factor loadings (a factor loading of greater than plus or minus 0.3 is considered significant) are present in factor one for the following statements: "I would be willing to change electricity company if I was offered 'green' electricity", "I think the way we make electricity causes air pollution", "I am not concerned about climate change", "The government should not be responsible for action to increase the amount of 'green' electricity", and "I think individuals should be responsible for investment in 'green' electricity". High factor loadings are present in factor two for the attitude statements: "The government should not be responsible for action to increase the amount of 'green' electricity", "I have no preference as to how my electricity is made", "'Green' power should be supplied at no extra cost", and "I think the way we make electricity causes air pollution". High factor loadings are present in factor three, for attitudinal statements: "I would not change electricity company just for cheaper electricity", "I would be willing to change electricity company if I was offered 'green' electricity", and "I think individuals should be responsible for investment in 'green' electricity".

In order to avoid overlap of factors, variables were assigned to one factor only. Those variables with factor loadings greater than +0.3 or less than -0.3 in more than one factor were allocated to the factor for which they had the highest factor loading.

Factor one contained the variables "I would be willing to change electricity company if I was offered 'green' electricity", "I think the way we make electricity causes air pollution", "I am not concerned about climate change", and "I think individuals should be responsible for investment in 'green' electricity".

Coding of these items ensured that higher scores were achieved by those respondents who were concerned about the environmental effects of electricity generation, and who felt themselves responsible for taking action to increase the amount of green electricity being used. This factor therefore could be appropriately described as environmental concern combined with individual responsibility and action.

Factor two contained the variables "the government should not be responsible for action to increase the amount of 'green' electricity", "I have no preference as to how my electricity is made", and "'green' power should be supplied at no extra cost".

Coding of these items ensured that higher scores were achieved by those respondents who were interested in their energy source, but who thought that government should take responsibility and that the cost to the consumer should be zero. This factor therefore could be appropriately described as environmental concern combined with government responsibility and zero cost.

Factor three contained the variable "I would not change electricity company just for cheaper electricity". Coding of the item ensured that higher scores were achieved by respondents who agreed with this statement, and who did not base their purchasing decision purely on price. This factor therefore could be described as electricity purchasing not price based.

- The first factor identified was environmental concern combined with individual responsibility and action.
- The second factor obtained was environmental concern combined with government responsibility and zero cost.
- The third factor identified was electricity purchasing not price based.

These three factors explained 59.8 percent of attitudinal variance: environmental concern combined with individual responsibility and action explained 30.2 percent; environmental concern combined with government responsibility and zero cost explained 16.1 percent; and electricity purchasing not price based explained 13.5 percent.

The factors identified would normally be checked for reliability. A reliability of 0.7 is normally considered acceptable. Reliability tests can only be performed on three or more variables, however. The reliability for environmental concern combined with individual responsibility and action was 0.67, which was an acceptable level to consider the factor a useful tool for further data analysis. The reliability for environmental concern combined with government responsibility and zero cost was low at only -0.20. Due to the very low reliability, this factor was not used for any further analysis. No measure of reliability for electricity purchasing not price based was possible due to the fact that only one variable was contained within this factor.

One final statistical test was possible on the identified factors before they were used in further data analysis. That was to measure the correlation between factors. Spearman's rank correlation coefficients for the three factors are shown in Table 3-4. The results indicated there was significant correlation between the first and second factors.

Table 3-4. Spearman's rank correlation coefficients for the three attitudinal factors

	Factor 1	**Factor 2**	**Factor 3**
Factor 1	1.000	0.327	-0.056
Factor 2		1.000	-0.067
Factor 3			1.000

Another look at the pattern matrix in Table 3-3 indicated that there was a significant level of association between the attitudinal statement "The government should not be responsible for action to increase the amount of 'green' electricity" and the other attitudinal items included in the first factor (factor loading = 0.572). Excluding this attitudinal factor from the second factor still results in a correlation of -0.302 between environmental concern combined with individual responsibility and action and environmental concern combined with government responsibility and zero cost. Not all of the correlation between the two variables could be accounted for in the attitudinal variable "The government should not be responsible for action to increase the amount of 'green' electricity". Therefore the statement was retained within environmental concern combined with government responsibility and zero cost.

In summary, factor analysis reduced the eight attitudinal statements to just three attitudinal factors. The three factors identified were:

- environmental concern combined with individual responsibility and action,
- environmental concern combined with government responsibility and zero cost,
- electricity purchasing not price based,
- environmental concern combined with government responsibility and zero cost had a low reliability score, so was excluded from further analysis.

3.7.3 The relationship between dependent and independent variables

In order to determine the relationship between one dependent variable and a group of independent variables, a multiple regression was completed. This was done in SPSS, and the regression procedure produced a model of the relationship.

Multiple regression was therefore used to test the first, second, fifth, sixth, seventh and eighth hypotheses as listed in Section 3.5 on page 57

3.7.3.1 Grouping independent variables into blocks

The regression was done using all the independent variables, in three blocks.

- The first block incorporated all the socio-demographic variables of interest (income, gender, social class, and age).
- The second block included the two attitudinal factors identified above (environmental concern combined with individual responsibility and action, and electricity purchasing not price based).
- The third block included the three variables regarding environmentally-related experience (whether the individual had visited the Energy Efficiency Advice Centre, whether the individual had visited the Ark, and whether the individual had visited the Ecohouse).

These independent variables were compared with two dependent variables, whether the respondent was willing to pay more and the level of premium they were willing to pay. The hypothesised relationships are shown in Figure 3-9.

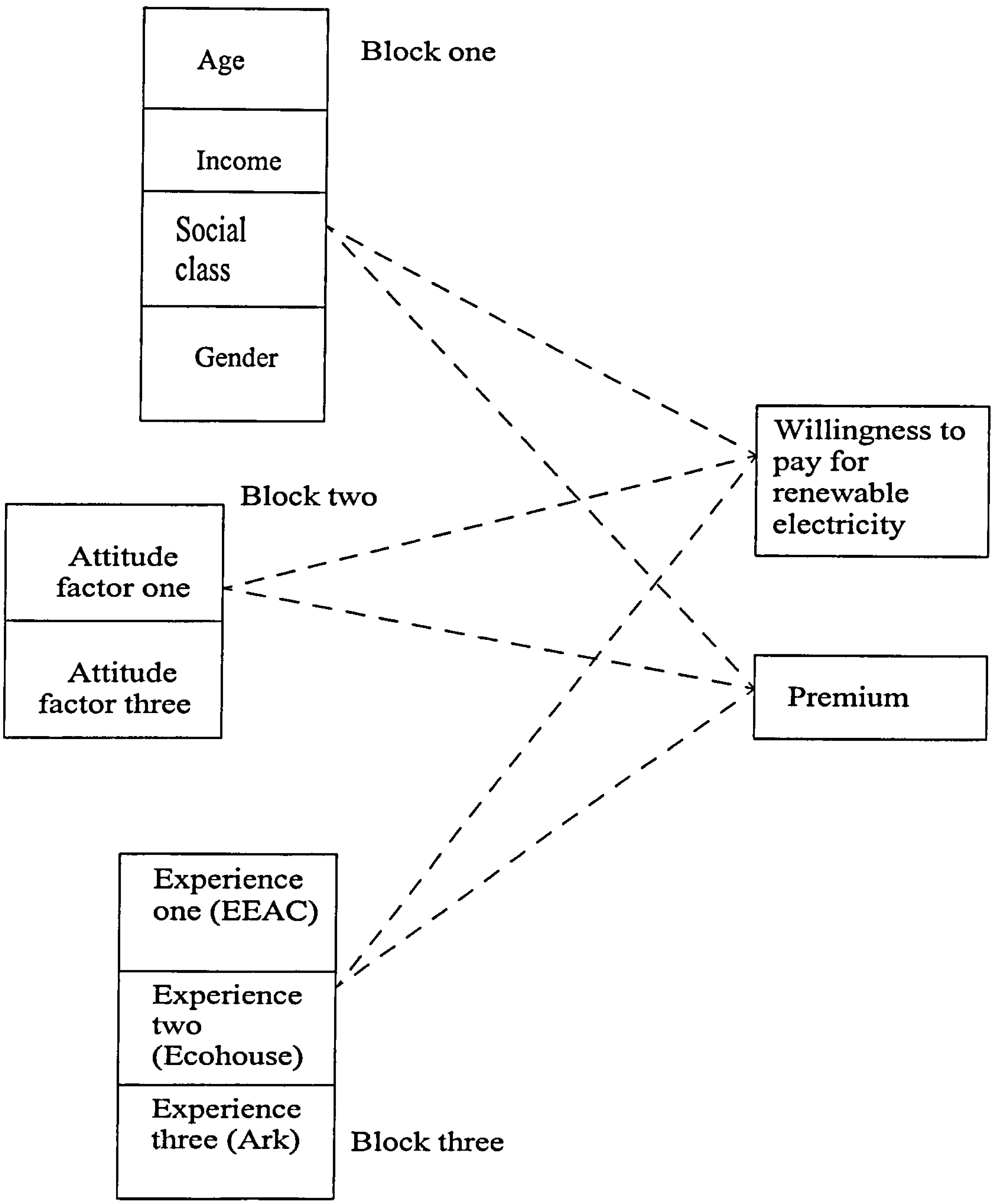

Figure 3-9. Relationship hypothesis between dependent variables (premium and willingness) and three blocks of independent variables

3.7.3.2 Multiple regression for willingness and premium with three blocks of independent variables

Once the independent variables had been grouped into blocks, several multiple regressions were completed in SPSS which used the stepwise method to eliminate non-significant variables.

The multiple regressions completed were:

- Willingness to pay and three blocks of independent variables.
- Premium and three blocks of independent variables.

Willingness to pay

The stepwise multiple regression indicated that three independent variables were significant predictors of willingness to pay: whether the respondent had visited the Ark, environmental concern combined with individual responsibility and action, and electricity purchasing not price based. These three variables could predict thirty two percent of variation in willingness to pay (adjusted R^2=0.323).

Environmental concern combined with individual responsibility and action was the most significant predictor due to its higher beta coefficient (Beta=0.410, t=10.442, sig.=0.000). Those who scored higher on this attitude factor (who were concerned about the environment and felt they should take action to purchase renewable electricity) were more likely to be willing to may more for renewable electricity. Electricity purchasing not price based (Beta=-0.239, t=-6.292, sig.=0.000) had a negative beta coefficient, which suggested that those who made electricity purchasing decisions on the basis of cheaper price were more likely to be willing to pay more for renewable electricity. The relationship between willingness to pay and whether the respondent had visited the Ark (Beta=0.193, t=4.912, sig.=0.000) was such that those who had visited the Ark were more likely to be willing to pay more for renewable electricity.

Premium

The same procedure was used for the regression analysis to determine the relationship between the three blocks of independent variables and the dependent variable premium. Results showed only three percent of variation in premium could be predicted by one variable: age (adjusted R^2=0.033). Age (Beta=-0.206, t=-2.119, sig.=0.037) had a negative beta coefficient because those in the lower age group were more likely to be willing to pay a higher premium for renewables.

3.7.3.3 Multiple regression of mediating variables

The multiple regression showed that no demographic variables were significant predictors of willingness to pay. However, it was possible that these variables were indirectly related to willingness through mediating variables. In order to determine whether the three predictors of willingness to pay were mediators, three further multiple regressions were completed.

- Environmental concern combined with individual responsibility and action, and demographic variables from the first block of independent variables.
- Electricity purchasing not price based and demographic variables from the first block of independent variables.
- Whether the respondent had visited the Ark and demographic variables from the first block of independent variables.

Environmental concern combined with individual responsibility and action

Stepwise multiple regression showed that age (Beta=-0.260, t=-4.278, sig.=0.000) and income (Beta=0.170, t=2.799, sig.=0.006) were predictors of environmental concern combined with individual responsibility and action, and these two variables could predict twelve percent of variation in this attitude factor (adjusted R^2=0.121). The beta weightings showed age the most significant predictor of this attitude factor, with the younger age group scoring higher (they were concerned about the environment and felt they should take action to purchase renewable electricity). Higher income groups also scored higher on this attitude factor.

Electricity purchasing not price based

Stepwise multiple regression showed gender (Beta=0.158, t=2.821, sig.=0.005) was related to this dependent variable, but only two percent of variation in this attitude factor could be predicted by this demographic variable (adjusted R^2=0.022). Women were less likely to make an electricity purchase decision based on price alone, and were therefore slightly more likely to score higher on this attitude factor.

Whether the respondent had visited the Ark

Stepwise multiple regression showed social classification (Beta=0.124, t=2.313, sig.=0.021), age (Beta=-0.127, t=-2.314, sig.=0.021) and income (Beta=0.236, t=4.268, sig.=0.000) were related to whether the respondent had visited the Ark, with nine percent of variation predicted by these three demographic variable (adjusted R^2=0.094). Income, with the highest Beta weighting, was the most significant predictor, with higher income groups more likely to have visited the Ark. Those in the lower age group were also more likely to have visited the Ark (due to the negative Beta coefficient), whilst those in higher social classification groups were more likely to have visited the Ark.

The relationship between willingness to pay, socio-demographic variables, attitude variables and experience variables is shown in the form of a diagram, in Figure 3-10.

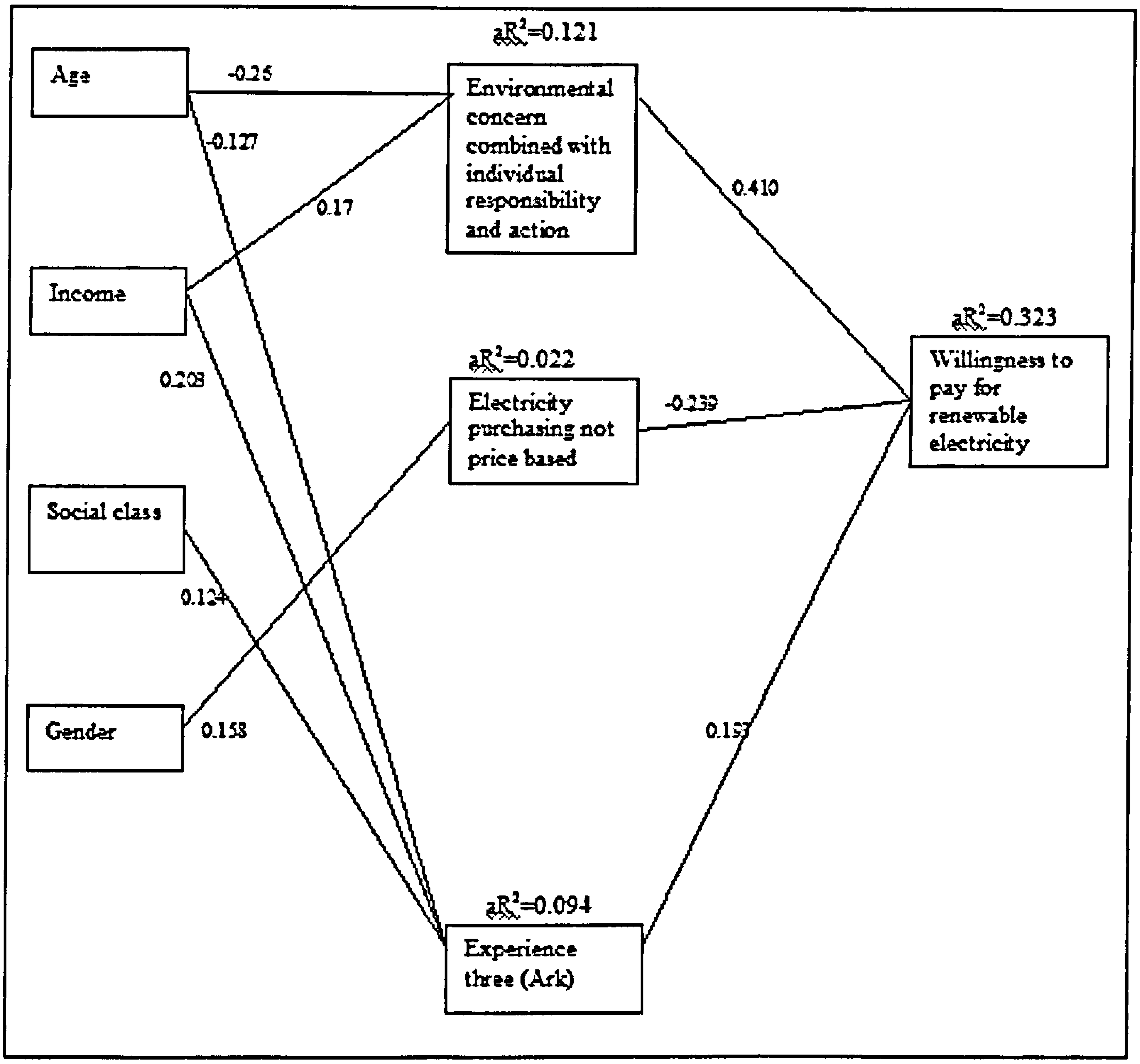

Figure 3-10. Diagrammatic representation of relationships between socio-demographic variables, attitudinal factors, experience variables and willingness to pay. Adjusted R^2 (aR^2) is a measure of the amount of variation that can be explained in one variable by other variables. The numbers shown next to the lines are the beta coefficients for those variables, showing the relative weighting of relationships

3.7.3.4 Multiple regression of willingness to pay and demographic variables: investigating possible reasons for the results of other research

One final multiple regression was completed. In this regression, willingness was the dependent variable and the independent variables were age, income, gender and social class. This was done to investigate whether demographic variables could be shown to be significant predictors of willingness to pay in the absence of other independent variables, since several surveys had found demographic variables to be significantly correlated with willingness to pay (Colbourne, Lorenzoni, Powell and Fleming, 1999; Lutzenhiser, 1993; Farhar, 1993; Farhar and Houston, 1996; Farhar, 1996; Ferguson, 1999; Rose, Clark, Poe, Rondeau and Schulze, 1997; Byrnes, Jones and Goodman, 1999).

Stepwise multiple regression showed that nine percent (adjusted R^2=0.091) of variation in willingness to pay could be predicted using income (Beta=0.167, t=2.864, sig.=0.004), age (Beta=-0.168, t=-2.944, sig.=0.003) and social class (Beta=0.121, t=2.192, sig=0.029). These results showed that higher income groups, higher social classes and the lower age group were all more likely to be willing to pay more for renewable electricity.

Hence, in the absence of attitudinal factors and environmental experience factors, socio-demographic variables age, income and social class could be shown as predictors of willingness to pay through multiple regression analysis.

3.7.3.5 Multiple regression summary

In summary, willingness to pay could be predicted using three variables, electricity purchasing not price based, environmental concern combined with individual responsibility and action, and whether the respondent had visited the Ark. This confirmed the first and eighth hypotheses. In turn, environmental concern combined with individual responsibility and action was related to demographic variables age and income, electricity purchasing not price based was related to gender, and whether the respondent had visited the Ark was related to age, income and gender. Environmental concern combined with individual responsibility and action was the most significant predictor of willingness to pay. Premium was very weakly linked to age. Multiple regression considering demographic variables only showed that these could be construed as significant predictors of willingness to pay if other independent variables were ignored.

3.7.3.6 The relationship between premium and willingness to pay

It was hypothesised in Section 3.5 that willingness to pay varied with the level of premium required (the fourth hypothesis). Figure 3-8 on page 70 showed this relationship. In attempting to describe this relationship statistically it was assumed that the relationship between willingness to pay and premium followed a similar format to that described in Farhar's work (1999) (see Equation 3-1 on page 47). Analysis of least squares showed that the line of best fit had the equation:

$$Y = 100e^{(-0.04)M - 1.25} \tag{3-2}$$

where Y was the cumulative percentage of people willing to pay and M was the percentage premium (correlation coefficient -0.97, showing the line fits the data well, significance -13.25, showing the relationship between the two variables is significant at $p<0.0005$).

3.7.3.7 Comparison of results with other domestic sector willingness to pay surveys

In Section 3.5 two hypotheses were proposed which are investigated here. The first was that willingness to pay varied with location, and that, in particular, differences would be expected between local and national surveys (the third hypothesis). The second was that willingness to pay varied with awareness of energy issues (the eighth hypothesis).

This sample was compared with a random sample of Leicester citizens, completed by Colbourne, Lorenzoni, Powell and Fleming (1999), to determine whether energy awareness was an influential factor on willingness to pay.

Results were also compared with random UK wide survey work completed by MORI (Parliamentary Renewable and Sustainable Energy Group, 1996), to determine whether there was any significant difference between the willingness to pay of the UK citizen and the Leicester citizen.

Using a difference of proportions test, no significant difference was found between the two Leicester samples when comparing proportions willing to pay more ($Z=0.184$, $p=0.573$). This indicated that those in Leicester who could be considered more aware of energy issues, by virtue of the fact that they had received energy efficiency advice in the past, were no more likely to be willing to pay more for renewables than the general city population. The hypothesis that awareness of energy issues was an influential factor on willingness to pay was not proved.

The proportions test, comparing the sample of the Leicester population who had contacted the Energy Efficiency Advice Centre and the MORI poll, showed a significant difference in the proportions willing to pay a premium ($Z = 6.037$, $p = 0.01$). The same result was found when comparing the MORI national sample and Colbourne's Leicester sample, a significant difference ($Z = 6.456$, $p = 0.001$) between the proportion of people willing to pay a premium. These results indicated that Leicester's population contained a significantly higher proportion of people willing to pay more for renewables than was found nationally.

A difference of means test indicated no significant difference in the mean premium for the national MORI sample compared with the Leicester sample who had contacted the Energy Efficiency Advice Centre ($Z = 1.676$, $p = 0.09$ two tailed) or compared with the random Leicester sample ($Z = 0.719$, $p = 0.47$ two tailed).

So whilst the proportion of people willing to pay more for renewables was greater in Leicester than nationally, the average premium they were willing to pay was not significantly different from the national average premium.

Given the work by Farhar (1999) on utility analysis of willingness to pay, and her derivation of a line of best fit for premium and willingness to pay, a similar line of best fit was attempted for three sets of willingness to pay results for the UK. In addition to MORI's national survey and Colbourne, Lorenzoni, Powell and Fleming's Leicester random sample were the results of the Ecotec survey (Ecotec, 1996) which looked at non-domestic willingness to pay. The results of the least squares line of best fit analysis for these three data sets are shown in Table 3-5. In this instance Y was the cumulative percentage who were willing to pay and M was the percentage premium.

Table 3-5. Characteristics of three UK willingness to pay surveys

	Random sample	MORI	ECOTEC
Format of best line	Ln (Y/100) = bX + a	Ln (Y/100) = bX + a	Ln (Y/100) = bX + a
a	-1.355	-1.847	-1.679
b	-0.066	-0.028	-0.121
Correlation coefficient	0.982	0.901	0.990
Significance	15.444	6.226	15.942
Relationship between Y and M	$Y=100e^{(-0.066M-1.355)}$	$Y=100e^{(-0.028M-1.847)}$	$Y=100e^{(-0.121M-1.679)}$

Correlation and significance results showed that the straight line fitted the data extremely well for all data sets. The results were also not dissimilar from Farhar's (1999) equation (note that in Farhar's data, M represented the tariff level in dollars and not pounds or percentage). Willingness to pay was plotted as a function of premium, for all four willingness to pay surveys, in Figure 3-11, with the line of best fit shown.

Results have therefore shown a significant difference in willingness to pay with premium. No significant difference in willingness to pay was found between a random sample of the Leicester population and the sample of Leicester citizens who had contacted the Energy Efficiency Advice Centre, which suggests that willingness to pay is not affected by awareness of energy issues.

3.8 Discussion of results

Based on previous research, this questionnaire was analysed to prove the following hypotheses.

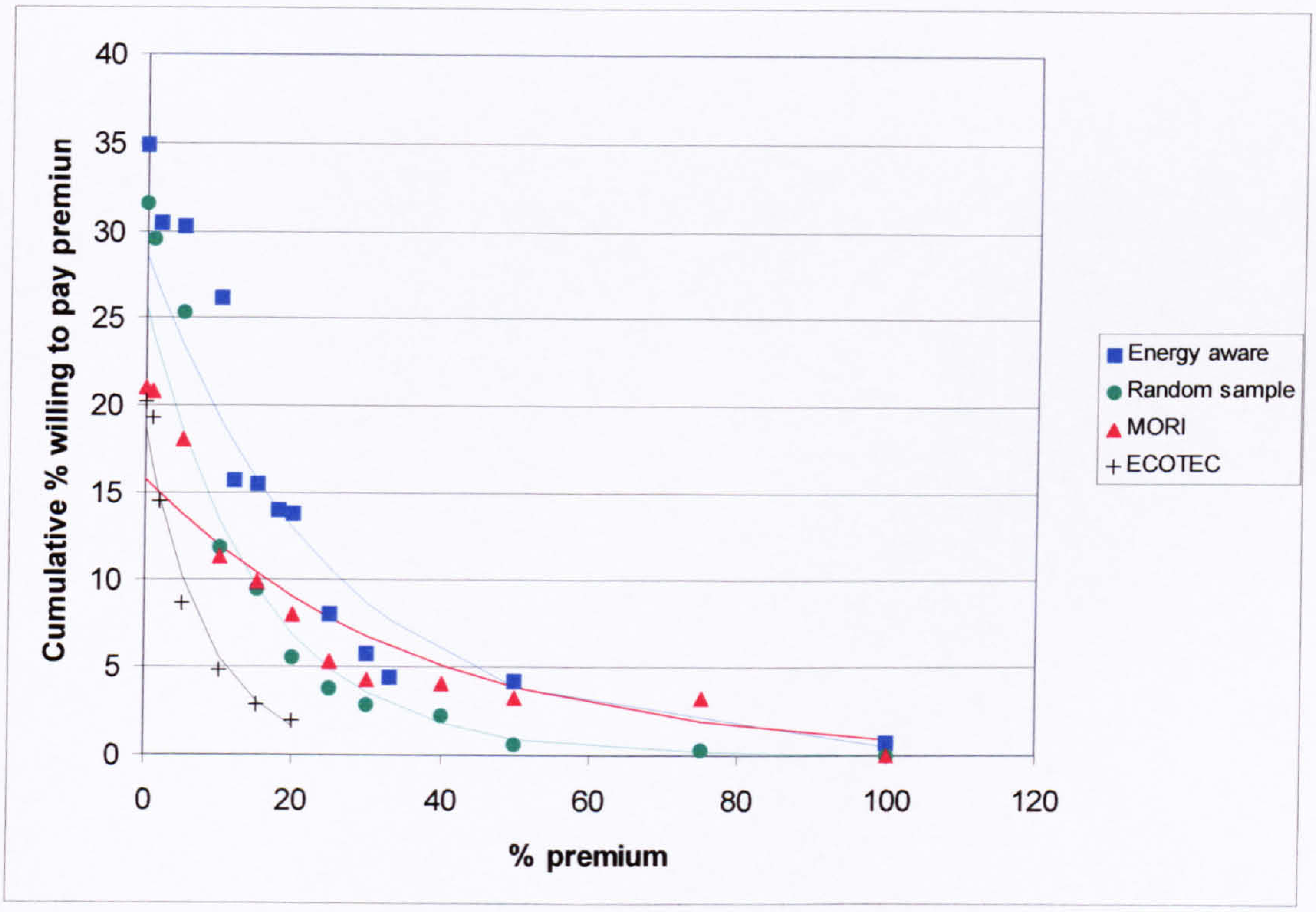

Figure 3-11. Cumulative willingness to pay for renewable electricity, for four samples, showing lines of best fit

- Hypothesis one: willingness to pay for electricity from renewable sources was related to attitude.
- Hypothesis two: willingness to pay for electricity from renewable sources was related to social class.
- Hypothesis three: willingness to pay for electricity from renewable sources was different at a local level compared to a national level.
- Hypothesis four: willingness to pay for electricity from renewable sources varied with the level of premium required.
- Hypothesis five: willingness to pay for electricity from renewable sources was related to age.

- Hypothesis six: willingness to pay for electricity from renewable sources was related to income.

- Hypothesis seven: willingness to pay for electricity from renewable sources was related to gender.

- Hypothesis eight: willingness to pay for electricity from renewable sources was related to awareness of energy issues.

Each hypothesis is discussed in the sections which follow.

3.8.1 Hypothesis one: willingness to pay for electricity from renewable sources was related to attitude

In order to investigate hypothesis one, the eight attitudinal variables were reduced to just three attitudinal factors by a process of factor analysis.

- environmental concern combined with individual responsibility and action,

- environmental concern combined with government responsibility and zero cost,

- electricity purchasing not price based.

Multiple regression showed that hypothesis one could not be rejected: whether an individual would be willing to pay more for renewable electricity was related to two of the attitudinal factors. Environmental concern combined with individual responsibility and action was the strongest predictor of willingness to pay in the multiple regression. Electricity purchasing not price based was not included in the multiple regression, due to its low reliability score.

3.8.2 Hypothesis two: willingness to pay for electricity from renewable sources was related to social class

Multiple regression showed that hypothesis two should be rejected: whether an individual would be willing to pay more for renewable electricity was not related to social class. Social class was, however, indirectly related to willingness to pay through a mediating variable: whether the respondent had visited the Ark (an environmental shop). Coding of items was such that the higher social classes were more likely to have visited the Ark.

Since previous research had supported this hypothesis, the finding was surprising. Three possible explanations could account for the different findings of this research to other surveys.

Ten categories of social class were used in the multiple regression. The regression analysis assumed a linear relationship between the independent variable (social class) and dependent variable (willingness to pay). Alternative ways of categorising social class may have resulted in a more linear relationship between the two variables, such that social class may then have become a significant predictor of willingness to pay.

Social class was determined from postcode and 1991 census survey data. Since the questionnaire was administered in 1999 it is possible that more recent data on social classification would have shown a relationship between social class and willingness to pay.

It is possible that those surveys which found a relationship between social class and willingness to pay only did so because they were comparing the dependent variable with just one independent variable, and did not complete a multiple regression. Because most surveys only completed regression between pairs of variables, their analysis also ignored the effect of attitudinal variables and variables relating to awareness of energy issues. Analysis of this survey did show, through multiple regression (Section 3.7.3.4), that social class was a weak predictor of willingness to pay under step wise regression, but once attitudinal variables were added to the regression model the effect of social class became insignificant.

3.8.3 Hypothesis three: willingness to pay for electricity from renewable sources was different at a local level compared to a national level

Comparison of survey results with the published results of MORI for the Parliamentary Renewable and Sustainable Energy Group (1996) showed that hypothesis three could not be rejected: whether an individual would be willing to pay more for renewable electricity was different at a local level compared to a national level. This was further confirmed by comparison of MORI results (Parliamentary Renewable and Sustainable Energy Group, 1996) with a random Leicester sample (Colbourne, Lorenzoni, Powell and Fleming, 1999), with a significant difference in the proportions willing to pay more for renewable electricity found. Both of the local surveys had significantly higher proportions willing to pay more than the national sample.

3.8.4 Hypothesis four: willingness to pay for electricity from renewable sources varied with the level of premium required

The survey results showed that hypothesis four could not be rejected: willingness to pay varied with the level of premium required. A greater proportion of the sample population were willing to pay at lower premium levels. Least squares fit showed the relationship between premium M (as a percentage) was related to the cumulative percentage of people willing to pay that premium Y by Equation 3-2 on page 83.

3.8.5 Hypothesis five: willingness to pay for electricity from renewable sources was related to age

Multiple regression showed that hypothesis five should be rejected: willingness to pay was not related to age. Age was, however, indirectly related to willingness to pay through the mediating attitude variable environmental concern combined with individual responsibility and action, and whether the respondent had visited the Ark. Negative beta coefficients for both these relationships indicated that the lower age group (adults) scored higher on the attitude factor and were more likely to have visited the Ark than the higher age group (pensioner).

It is possible that those surveys which found a relationship between age and willingness to pay did so because they only considered one independent variable at a time instead of completing a multiple regression of all independent variables, or they may have considered only socio-demographic variables and not incorporated attitudinal variables into their analysis. A multiple regression was completed which excluded attitudinal variables and environmental experience variables (Section 3.7.3.4), and the results showed age was a weak predictor of willingness to pay if these other independent variables were ignored.

3.8.6 Hypothesis six: willingness to pay for electricity from renewable sources was related to income

The multiple regression showed that hypothesis six should be rejected: willingness to pay was not related to income. Income indirectly related to willingness to pay through the mediating attitude variable environmental concern combined with individual responsibility and action, and whether the respondent had visited the Ark.

Previous research findings had shown a relationship with income and willingness to pay, so this was a surprising finding. However, these surveys generally considered the relationship between willingness to pay and one independent variable at a time. This can give misleading information, since this survey showed through multiple regression (Section 3.7.3.4) that income was a weak predictor of willingness to pay until the attitudinal variables were added to the regression.

3.8.7 Hypothesis seven: willingness to pay for electricity from renewable sources was related to gender

Multiple regression showed that hypothesis seven should be rejected: willingness to pay was not related to gender. Gender indirectly related to willingness to pay through attitude factor electricity purchasing not price based. This relationship indicated that females were less likely to make an electricity purchasing decision on the basis of price alone. And those who were less likely to base the decision on price were more likely to be willing to pay more for renewables.

3.8.8 Hypothesis eight: willingness to pay for electricity from renewable sources was related to awareness of energy issues

Multiple regression indicated that willingness to pay could be partly predicted based on whether the respondent had visited the Ark. This would imply that hypothesis eight should not be rejected: willingness to pay was related to awareness of energy issues. This would, however, assume that the experience of visiting an environmental shop (the Ark) resulted in increased awareness of energy issues. These would appear unlikely, given the nature of the Ark. The variable would perhaps be a better indicator of environmental awareness and environmental purchasing attitude.

In comparing the results of the surveyed with those of Colbourne, Lorenzoni, Powell and Fleming (1999) no significant difference was found in the proportions willing to pay more. If the respondents of this survey were considered more aware of energy issues by virtue of the fact that they had received information from the Energy Efficiency Advice Centre, then the results of this comparison would imply that hypothesis eight should be rejected.

Therefore, the results appeared inconclusive in this matter. This was due to conflicting ways of categorising respondents as being more aware of energy issues. If all respondents were classed as aware, the hypothesis was rejected. If only those who visited the Ark were classed as aware, the hypothesis was not rejected. A more accurate measure of energy awareness was necessary before this hypothesis could be suitably investigated.

The results of this survey could, therefore, be considered representative of the population of Leicester rather than just representative of those who had contacted the Energy Efficiency Advice Centre, since no significant statistical difference between the two samples was found.

3.9 Summary

Results indicated that there was a general interest in renewable electricity from a significant minority of the Leicester population who had contacted the Energy Efficiency Advice Centre: 35+/- 3.59 percent. Those who were willing to pay more had an average premium they were willing to pay of 19.11 +/- 2.48 percent.

The proportion of respondents who were willing to pay more was significantly higher than for results from a national survey (Parliamentary Renewable and Sustainable Energy Group, 1996), showing that the proportion willing to pay was lower nationally than locally.

However, the sample of those who had contacted the Energy Efficiency Advice Centre contained a proportion willing to pay more for renewable electricity which was not significantly different from the proportion willing to pay more in a random sample of the Leicester population. The results of this survey could, therefore, be considered representative of the population of Leicester rather than just representative of those who had contacted the Energy Efficiency Advice Centre.

The three attitudinal factors which were derived from factor analysis were:

- environmental concern combined with individual responsibility and action;
- environmental concern combined with government responsibility and zero cost;
- electricity purchasing not price based.

Multiple regression indicated that three independent variables could explain thirty two percent of variability in willingness to pay. These variables were environmental concern combined with individual responsibility and action, electricity purchasing not price based, and whether the respondent had visited the Ark. Multiple regression also indicated that no variable could explain any significant part of the variation in premium.

Therefore, test results proved the hypothesis that willingness to pay was influenced by attitude. Test results did not, however, prove the hypothesis that willingness to pay was influenced by disposable income, gender, age or social class.

These results were surprising, given the literature which had shown a link between willingness to pay and socio-demographic variables. However, these relationships had been derived by using only one independent variable to explain willingness to pay. Multiple regression incorporated all the investigated variables such that only those with the most significant relationship with willingness to pay were identified.

Results showed that as premium increased, the percentage of people willing to pay that premium decreased. Using regression analysis it was possible to find the line of best fit which related these two variables. The cumulative percentage of people willing to pay a premium for renewable electricity was related to the premium by:

$$Y = 100e^{(-0.04)M - 1.25}$$

where Y was the cumulative percentage of people willing to pay and M was the percentage premium.

Chapter 4: Demand and supply modelling

4.1 Introduction

This chapter concentrates on energy modelling. An energy model review is presented, and appropriate model for the investigation is chosen. A sensitivity analysis of the model is then presented. The model is then used to develop several scenarios which predict renewable electricity demand, as a result of green tariff uptake, to 2025. Green tariff uptake is modelled for three different tariff levels, which are representative of products available in the market place. The uptake at these tariff levels are estimated based on the results of the willingness to pay survey. Finally, two scenarios are developed which consider green tariff uptake as following a product lifecycle curve (rather than being equal to the stated willingness to pay of the sample population) to predict renewable electricity demand to 2025.

4.2 Modelling methods for predicting market change

If demand were to be viewed from an aggregated level then many simple models exist which have predicted growth in energy demand based on economic growth and population growth figures. Use of Gross Domestic Product (GDP), and its relationship with energy, to predict future energy demand was subject to several inaccuracies, however. Gross Domestic Product did not indicate the structure of an economy, for example some economic activity could go unreported in national GDP statistics. Also, GDP was a monetary unit subject to exchange rate conversion, making international comparisons subject to heavy exchange rate influence.

Siddayao (1986) evaluated several different econometric approaches for the estimation of energy demand. He found that the principal determinants of demand were considered to be:

- the possible prices of energy;
- the prices and availability of substitutes or compliments;
- the price of other commodities which compete for disposable income;
- disposable income;
- buyer preferences;
- buyer expectations;
- technology (Siddayao, 1986).

Energy model results could be very sensitive to assumptions made about cost, performance and potential of technologies. Due to the uncertainties of many assumptions, it was common for models to generate several scenario predictions such that the uncertain parameter could take a range of values and the impact of variation in the parameter could then be highlighted. Input-output models did allow for studies of energy demand at a relatively disaggregated sectoral level, avoiding some of the disadvantages of aggregating energy demand.

The modelling of energy demand could involve a series of complex decisions which will ultimately affect the model outcomes. For example, where should the boundaries of the analysis be placed? Should the analysis include commercial and non-commercial energy sources, and should it include embodied energy? The definition of the boundary could determine, to an extent, which factors in the model are to be independent and which dependent. Once the boundary has been set, how is the energy entering the system measured? Conversion of energy from one set of units to another requires fairly detailed knowledge of the equipment used with that energy type. Aggregating information into one holistic figure for energy input means a loss of useful data. There is a difference in the quality of fuels that is important for substitution considerations. Aggregation would lose that level of information.

The ideal energy model for the purpose of this research would incorporate input parameters such as disposable income, willingness to pay for green power, technology trends, population and household trends, and the electricity intensity of households. The output of the ideal model would therefore predict electricity demand, and the renewables contribution to that as a result of green power schemes. Such a model was unlikely to exist in the general format described. The model review which follows therefore considered energy models which were available, and their suitability in determining green power demand for the domestic sector.

4.3 Energy model review

Five models were reviewed to determine their suitability for use in this stage of the investigation. Brief descriptions of each are given below.

4.3.1 MARKAL

The MARKet ALlocation model was developed by the International Energy Agency. It was the model used by Energy Technology Support Unit to analyse the potential contribution of different conventional and renewable energy sources to the future electricity generation mix. The model was used to produce estimates of deployment for various technologies at five year intervals to 2035 (Energy Technology Support Unit, 1994). As well as deployment estimates, the model allowed investigation of environmental constraints such as reduction of carbon dioxide, oxides of sulphur and oxides of nitrogen, and allowed a sensitivity analysis of uncertainties in technology price and performance. Since the model produced least cost solutions based on a perfectly performing market, this was seen as a weakness for the demand side sectors. This was because purchasing decisions were, in reality, based on factors other than price. Access to this model was restricted to approved organisations within OECD countries (see Ybema and Kram (1997) for a non UK application of MARKAL). For the UK, Future Energy (formally Energy Technology Support Unit) was the approved body for the use of the MARKAL model, and they had developed the necessary databases of UK statistics to run the model.

4.3.2 Department of Trade and Industry 1993 Domestic Sector Energy Model

The Department of Trade and Industry periodically published Energy Papers, which analysed and predicted energy demand for the UK. The most recent forecast available, in Energy Paper 68 (Department of Trade and Industry, 2000a), used a specialist domestic sector energy model which was developed for the purpose. The model was sub-divided into: space and water heating; cooking; and lights and appliances (Marsh, 1997). The model for space and water heating used historic data for take-up of central heating, combined with equations to estimate the central heating fuel type (gas, electric, petroleum or solid fuel). Average consumption levels for each heating type were then used to predict a total energy demand for each fuel type. For the cooking sub sector, the model used an econometric take-up equation for electric cookers. Cooking fuels were assumed to be either electricity or gas. The percentage of households owning gas cookers was then derived from the total number of households and the estimated take-up of electric cookers from the aforementioned equation. Using historic average consumption data, a consumption of gas or electricity per cooker was obtained, which was then used with the number of cookers to calculate total gas and electricity demand from cooking. Consumption data for lights and appliances, with electricity as the only fuel, summed the product of ownership level and average consumption for various appliance types. This was then multiplied by the number of UK households, to give a UK electricity demand figure due to lights and appliances. Within this sub sector analysis was an analysis of electricity demand resulting from nine major appliances and non-major appliances.

Whilst the model predicted energy demand from domestic energy use in some detail, there was no determination of the fuel used to meet the electricity demand which was predicted. The model therefore could not determine the renewable electricity demand which may contribute to domestic sector electricity demand.

4.3.3 Dynamic Regional Energy and Emissions Assessment Model (DREAM)

In principle, an energy model should quantify the most significant areas of energy demand within a region, and assess various energy management options to meet policy aims. The Dynamic Regional Energy and Emissions Assessment Model (DREAM) was specifically designed to overcome many of the problems associated with other commercially available models, and was also designed with the Local Authority user in mind (Boyle, 1994). The first version was completed for use with Leicester City data in 1993, and in 1995 it was updated for a rural environment with Leicestershire county data (De Montfort University and Leicestershire County Council, 1995).

The model consisted of four sub-models; the domestic, services, industrial and transport sector sub models. The 1993 version for Leicester City specifically included combined heat and power (CHP) and district heating. For the domestic sector, energy demand in housing was considered in terms of space heating, water heating, cooking, and lighting and appliances. The proportion of energy demand met by the different fuel types was calculated (accounting for efficiencies) and the emissions impact was also determined. In order to consider policy implications of energy management options, three scenarios were developed for the Leicester City and Leicestershire County 1993 and 1995 versions. These scenarios were called "Business as usual", "Technical fix" and "Green". The model authors, Godfrey Boyle and Helena Titheridge, combined with Paul Fleming of De

Montfort University to produce an analysis (Titheridge, Boyle and Fleming, 1996) of the validation of the model.

The domestic sector of the model was split into several sub-sectors, all of which interrelated in some way. The demand for energy was determined by the "water heating", "space heating", "cooking", and "lights and appliances" sub-sectors (Titheridge and Boyle, 1996). The model required a large amount of data for the domestic sector. It did, however, analyse electricity supply as a combination of renewable, combined heat and power and conventional fuel sources.

4.3.4 Residential End-Use Planning System (REEPS)

The Residential End-Use Energy Planning System (REEPS) was developed by the Electric Power Research Institute (EPRI) in the United States. It was designed to allow the user considerable control over the relationships within the model, and modelled various energy end-uses in the residential sector.

The final results from the model could indicate the aggregated energy demand from the residential sector as a result of forecasted appliance purchasing patterns. These appliances included heating and cooling energy demand, as well as lighting, cooking, dryers, freezers and refrigerators. This model did calculate energy demand (including electricity) for the domestic sector in some detail, but did not subdivide electricity demand into renewable and conventional sources (Koomey, Brown, Richey, Johnson, Sanstad and Shown, 1995).

4.3.5 The Oak Ridge Financial Model (ORFIN)

This model was developed in the US and simulated a single utility interacting with the market. This allowed the user to examine the impact of certain variables on utility production costs, assets, incomes, losses and rates. The key inputs to the model related to: non-generation operating costs, non-generation capital costs, power purchase contracts, utility-owned generating units, wholesale-market prices, customers, retail wheeling, and finances.

The model considered the situation of the utility as indicated by user inputs and then calculated generation, contract purchases and wholesale-market activity for the utility, given the demand of customers. The model forecasted electricity supply rather than demand, based on market simulation which included sectors other than the domestic sector. Allocation of domestic sector electricity demand, and subdivision of electricity generation into renewable electricity, was not possible with this model (Energy Information Administration, 1996).

4.4 The choice of Dynamic Regional Energy and Emissions Assessment Model (DREAM) as a suitable model

Following a review of available energy models for the UK, the Dynamic Regional Energy and Emissions Assessment Model (DREAM) was selected as the most appropriate for this research. This was primarily due to the fact that DREAM was the only commercially available model which calculated the contribution made by renewable energy to the electricity generation mix for domestic sector electricity demand.

DREAM was specifically designed to enable users to quantify the effects of energy management options. The model was first developed as part of a European Commission project - "Development of information systems and computer models for improving energy management in the urban environment" (Leicester City Council, Area Metropolitana de Barcelona, Open University and Universitat Autonoma de Barcelona, 1994). The first version was completed for use with Leicester City data in 1993, and in 1995 it was updated for a rural environment with Leicestershire county data (De Montfort University and Leicestershire County Council, 1995). The model was improved in 1996 for Leicester City under EPSRC funding (Boyle and Titheridge, 1998). The 1996 version of the model was used in this research.

The model consisted of four sub-models; the domestic, services, industrial and transport sector sub models. This version included combined heat and power (CHP) and district heating. For the domestic sector, energy demand in housing was considered in terms of space heating, water heating, cooking, and lighting and appliances. The proportion of energy demand met by the different fuel types was calculated, and this incorporated renewable energy sources. These characteristics matched the criteria required for the research.

4.5 DREAM domestic sector sensitivity analysis

A sensitivity analysis of DREAM domestic sector model was carried out, to determine which parameters the model was most sensitive to. During the later stages of this research it was necessary to create new scenarios for DREAM. This involved the manipulation of the model's parameters, and relationships between parameters. An understanding of the operation of the model, and the sensitivity of the model to particular parameters, was therefore necessary.

A full description of the methodology and results for the sensitivity analysis is contained in Appendix II. A discussion of methodology and results is presented here.

4.5.1 Variation of the input parameters

The DREAM model used sixty four input parameters, of which fifty nine could logically be varied for a sensitivity analysis (see Appendix II for a full list of input and output variables). Seventeen of these related to renewable energy, and forty two were not related to renewable energy.

In the first stage of the sensitivity analysis the fifty nine variables were each altered by a positive and negative increment of ten percent. The percentage change in output variables was then compared with a base case to determine which input variables produced a significant (four percent or greater) change in output variables.

For the forty two non-renewable variables the base case used was the "business as usual" scenario. The outputs were most sensitive to changes in the number of residents, number of people per household, the heat loss parameter, the internal temperature and the floor area. In each case, these input variables produced a significant change in output to several output variables.

For the seventeen renewable input variables a base case was created (Appendix II contains details of the input variable settings for this base case). Whilst fifteen of the seventeen variables produced a significant variation in output variables, only one output variable was affected in each case. The input and output variables related to the same renewable energy source. All other output variables did not show any significant variation, so it was not considered that the model was sensitive to any of the renewable input variables.

Therefore the model was shown to be most sensitive to variations in the number of residents, the number of people per household, the heat loss parameter, the internal temperature and the floor area.

4.5.2 Output parameters showing most sensitivity to variations in input

After determining a suitable sub sector of input variables which the model was most sensitive to, it was necessary (in order to reduce the number of variables under consideration to a manageable level before extending the sensitivity analysis further) to also determine a group of output parameters which would be representative of the model. This was done by first listing the changes to all output variables for the five input variables chosen. The percentage changes were then compared and ranked, and the five ranks added together.

Ranking the output parameters in order of their percentage change (following a ten percent change in input variable) indicates that the greatest change occurred in the following ten outputs: monthly gas, monthly oil, annual rolling gas, monthly CHPDH, annual rolling oil, total emissions (gas carbon monoxide), total emissions (gas nitrous oxides), total emissions (gas methane), total emissions (gas carbon dioxide) and total fossil fuel supplied (gas).

From the ranking exercise it was clear that, for the five chosen input variables, gas-related output parameters were most sensitive to change. Five output parameters were chosen from the top ten ranked outputs, and not all were gas-related, to ensure representation of information on other fuel types. These were: monthly gas, monthly oil, monthly CHPDH, annual rolling oil and total emissions (gas carbon monoxide).

4.5.3 Further investigation of the sensitivity of the model to single variables

For each of the five input variables identified in the preliminary analysis, a more detailed investigation of the model sensitivity was carried out. Each input variable was altered within the range of plus ten percent and minus ten percent, in two percent increments. This meant a further forty runs of the model. Results clearly indicated that the percentage change in outputs was linear with the change in input, for all five variables investigated (over the range of plus ten percent and minus ten percent change in input variable). Full results can be found in Appendix II. Therefore, for the input parameters investigated, it would be possible to estimate the direction and magnitude of a change in one of the representative output variables for a given change to a single input variable (assuming that linearity is maintained outside of the range investigated).

4.5.4 Sensitivity to the model of a combination of variables

A logical progression within the sensitivity analysis was to consider the effect of varying more than one variable. There were five variables under investigation, and there were a potential ten combinations of two variables, ten combinations of three variables, five combinations of four variables and one combination of five variables.

The two variable combinations were investigated first. For each variable pair, a combination of positive and negative ten percent increments was investigated. With four possible increment combinations for each pair, and ten possible pairs, it was necessary to complete forty runs of the model. A full set of results for combinations of two input variables is shown in Appendix II.

Since there was such a potentially large number of future increment combinations for the three variable (eight combinations per trio), four variable (sixteen combinations per quad) and five variable (thirty two) combinations, it was necessary to determine whether all increment combinations would need to be investigated.

Therefore, during the two variable investigation, the percentage change in outputs as a result of the pair was compared with the sum of the percentage changes for the individual variables. A good correlation was evident between the sum of individual sensitivity and combined sensitivity, as shown in Figure 4-1 for one example pairing. Therefore for any number of input variables, an estimate of the magnitude of change in a representative output variable could be made, if changes to the inputs were known. This meant that not all combinations of input increments required investigation.

When investigating combinations of three, four and five variables only a positive increment of ten percent was added to all input variables. This resulted in a further sixteen runs of the model. In order to confirm the predictability of output parameters, the combined effect of individual input variables was compared with the effect of input variable combinations in each case. These results are shown in Appendix II.

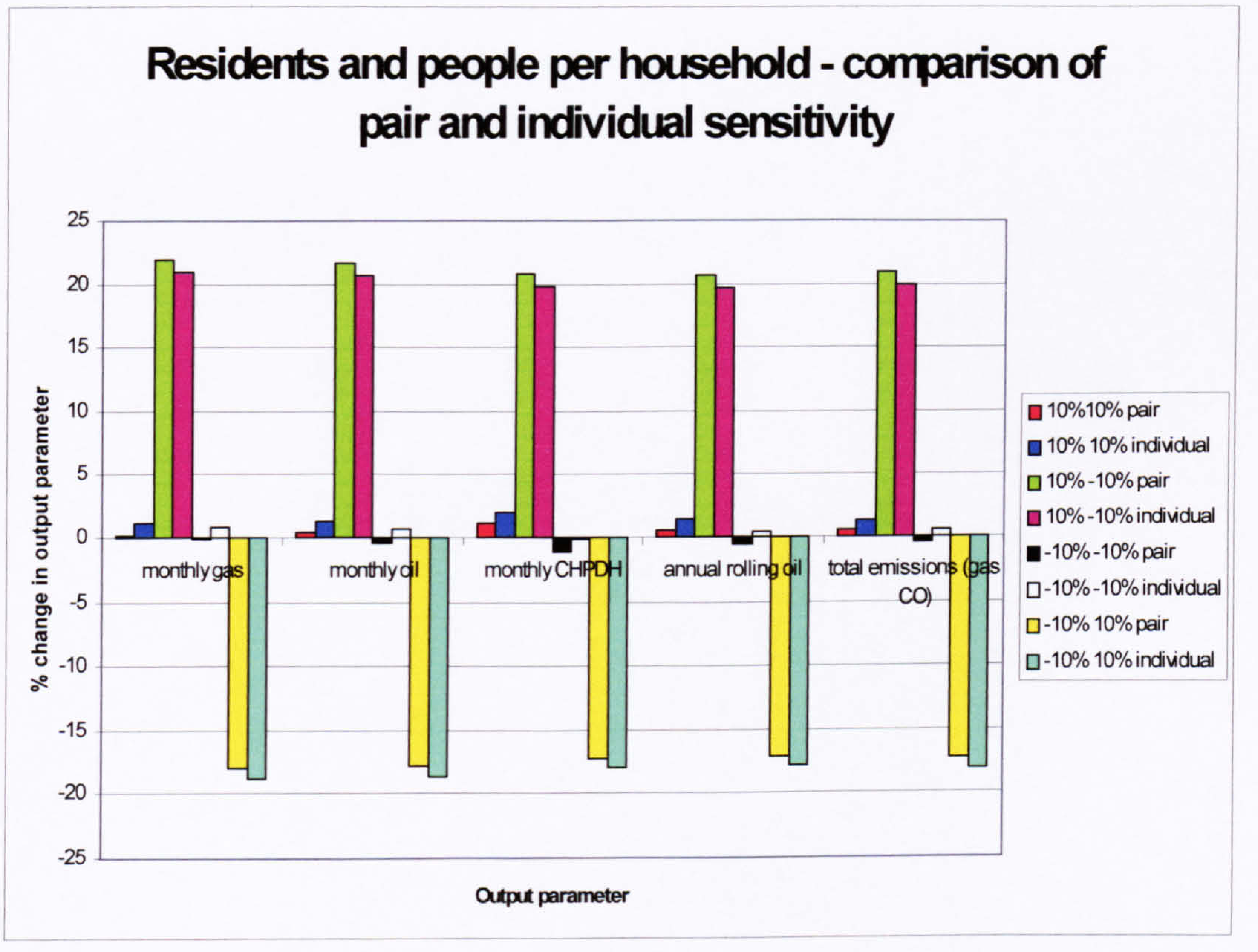

Figure 4-1. Comparison of the effect of individual sensitivity and combined sensitivity of two variables - residents and people per household

4.5.5 Conclusions of sensitivity analysis

The DREAM model was most sensitive to internal temperature, heat loss parameter, number of residents, people per household and floor area (in that order). An increase in internal temperature, heat loss parameter, number of residents and floor area all resulted in an increase in energy demand, and hence representative outputs. An increase in the number of people per household led to a reduction in energy demand, and representative outputs.

The change in an output variable was directly proportional to the change in the input variable for internal temperature, heat loss parameter, number of residents and floor area. The change in an output variable was inversely proportional to a change in the number of people per household.

For combinations of variables, the effect was approximately the same as the sum of each variable's individual effect on representative output parameters. These results indicated that the model used linear relationships between variables in order to determine energy demand, and that combinations of input changes had a predictable effect.

4.6 Scenarios which incorporate green electricity tariffs

4.6.1 Determining demand for green electricity tariffs

In developing scenarios within Dynamic Regional Energy and Emissions Analysis Model (DREAM), it was assumed that the uptake of a green electricity tariff could be predicted based on the results of the willingness to pay survey. This makes use of Equation 3-2 on page 83, Chapter 3:

$$Y = 100e^{(-0.04)M - 1.25}$$

DREAM calculated electricity demand based on complex assumptions about fuel shares for space heating, water heating, and cooking, lights and appliances. In order to estimate the demand for renewable electricity, it was necessary to assume that all domestic customers within the DREAM model were assigned an average electricity demand. Therefore, if fifteen percent of domestic customers were predicted to choose a green electricity tariff, it was assumed that fifteen percent of total modelled electricity demand would be required to meet the resultant green tariff demand. This was not an accurate assumption to make on an individual household scale, since individual households vary greatly in their electricity demand, but it was a relatively fair assumption to make based on the current workings of the electricity market. This was because, despite great variations in electricity demand between similar households, the electricity trading system used only two standard demand profiles for metering of the domestic market.

Once the predicted demand for renewable electricity was estimated, based on total electricity demand and the percentage of customers demanding a green electricity tariff, then it was possible to begin building the scenario which would match the green electricity demand with renewable electricity supply. In DREAM, a scenario was built by varying the amount of renewable electricity generation equipment installed. It was possible to meet green electricity demand in DREAM using the following technologies:

- wind;
- photovoltaic;
- hydro;
- biomass CHP; or
- a combination of the 4 technologies.

In developing the DREAM scenarios, it was necessary to choose a tariff premium for investigation. From this, tariff uptake could be estimated. It was decided that three tariff levels would be investigated: two percent, eight percent, and fifteen percent. Eight percent and fifteen percent tariffs were available at the time in the UK market (2001) from Yorkshire Electricity and SWEB, and so were chosen as representative premiums for the market in general. In 2002 similar tariff levels continued to be made available in the UK market place from Servista (around fifteen percent premium for GreenPower tariff) and ScottishPower and MANWEB (around seven percent for Green Energy tariff). A comparison of generation costs for wind technology (average 2.88 p/kWh for large scale wind and 4.18 for small scale wind under NFFO-5) compared with fossil technology (1.8 - 2.2 p/kWh for new combined cycle gas turbine and 2.6 - 3.25 p/kWh for new coal) confirms these proposed tariff levels as representative of a possible range of increased costs associated with renewable electricity supply (British Wind Energy Association, no date). A two percent tariff was also investigated, since uptake at this level was potentially much higher and therefore perhaps better able to contribute to Government renewable electricity targets.

Table 4-1 shows the tariff uptake associated with the three tariff premiums investigated, based on Equation 3-2 on page 83.

Table 4-1. Tariff premiums, and predicted uptake, based on willingness to pay results

Premium	Percentage uptake
2%	26.45%
8%	20.81%
15%	15.72%

Based on electricity consumption data for 2001 (Department of Trade and Industry, 2002), the domestic sector consumed 115,336 GWh of electricity (total electricity consumption 333,806 GWh). To deliver on the Government's ten percent target in the domestic sector alone, 28.94 percent of domestic demand would have to be met from renewable energy sources. It is therefore clear based on domestic sector electricity demand in 2001 that a level of renewable electricity demand close to the ten percent target will only occur at premiums close to two percent, provided all stated willingness to pay is transferred into action on purchasing a green tariff. This also assumed that the green tariff chosen by the customer delivered one hundred percent of electricity demand from renewable sources, rather than being of the green fund form, for example.

In developing the green tariff scenarios, it should be noted that business as usual DREAM scenarios included no electricity generation from wind, hydro, photovoltaic or biomass sources. The DREAM scenario was based on data for the city of Leicester, but could easily be adapted for other regions or cities, since many of the assumptions of the model were based on general characteristics of UK households and very little data was specific to Leicester.

4.6.2 Wind

In order to develop three scenarios for wind generation (to meet electricity demand resulting from a two percent, eight percent and fifteen percent tariff) certain assumptions were made.

It was assumed that all turbines would be the same size (DREAM was not capable of modelling multiple turbine dimensions). The turbine diameter variable was fixed at a value of 68 metres (which equated to a 1MW turbine at the then current technology specifications).

It was assumed that no installation could occur prior to month 216 (January 2002) and that the installation rate would gradually increase over time until enough generation capacity had been installed. This meant that all scenarios developed could not meet one hundred percent of the renewable electricity demand immediately, but that generation would increase over time until local generation was able to match local demand.

In investigating scenarios for generation of electricity by wind, an error in the model was found and corrected. The equation for the variable "monthly wind energy supplied" was changed from:

mthly wind energy supplied = 1.3 x array efficiency x month length x number of turbines x (wind speed)^3 x π x (turbine diameter / 2)^2 x turbine coefficient of performance **(4-1)**

to incorporate a factor of a half as shown:

mthly wind energy supplied = 0.5 x 1.3 x array efficiency x month length x number of turbines x (wind speed)^3 x π x (turbine diameter / 2)^2 x turbine coefficient of performance **(4-2)**

This derives from the equation for the power in the wind (Boyle, 1996).

$$\text{power} = 0.5 \times \rho \times A \times v^3 \qquad \textbf{(4-3)}$$

ρ is the density of air (assumed, in DREAM to have a value of 1.3 kg/m^3). A is the swept area of the turbine (equal to the turbine diameter, divided by two, squared). v is the wind speed. The equation originally used in DREAM had omitted the factor of 0.5.

Despite the correction of this error, results obtained were an order of magnitude greater than that expected, in that, by month 504, over 1000 1MW turbines were required to meet the green electricity demand for a two percent tariff. Given an annual average UK household electricity consumption of 4.2 MWh (Department of Trade and Industry, 1996), a 600 kW machine can typically supply enough electricity per year for around 400 homes. In the DREAM business as usual scenario, there are 138,943 households in month 0 and 184,712 by month 504. It follows that a scenario to meet demand for a two percent tariff would require approximately 93 turbines (600 kW) in month zero and 122 in month 504. Initial results were a factor of ten away from those expected.

Several variables were then checked to ensure they were of the correct order of magnitude. Given the relative importance of wind speed in the equation for monthly wind energy supplied, the variables for calculating wind speed were checked. The annual average wind speed for potential sites was set at a relatively low default level of 2.89 metres per second. Changing this to six metres per second immediately gave results of the order of magnitude expected (demand resulting from a two percent tariff could be met using 120 turbines in month 504).

In order to obtain an accurate wind speed figure for Leicester a wind speed database was used. First, the Ordinance Survey coordinates for the City of Leicester were obtained by downloading the digitised border information from UKBORDERS (UKBORDERS, date unknown). The Department of Trade and Industry NOABL wind speed data base (Department of Trade and Industry, date unknown) was used to find the annual average wind speed for each 1km square within the city boundary (as defined by the Ordinance Survey data). An average of these values was taken as being representative of the annual average wind speed of potential sites in the city. The "annual average wind speed" variable was set at this value, 6.15 metres per second (at a height of 45m above ground).

Finally, a scenario was built to determine the electricity generation from wind technology based on changes to the variable "number of turbines". The values used, for the three scenarios, are shown in Table II-12 of Appendix II. Demand for green electricity as a result of green tariff offerings could be met by wind energy alone, using 155 (two percent tariff), 90 (eight percent tariff) or 68 (fifteen percent tariff) turbines in month 504 (year 2026). The electricity generated by wind power under the three scenarios is shown in Figure 4-2.

4.6.3 Hydro

In order to develop three scenarios for hydro generation (to meet electricity demand resulting from a two percent, eight percent and fifteen percent tariff) certain assumptions were made. It was assumed that no installation could occur prior to month 216 (January 2002) and that the installation rate would gradually increase over time until enough generation capacity had been achieved. This meant that all scenarios developed could not meet one hundred percent of the renewable electricity demand immediately, but that generation would increase over time until local generation was able to match local demand.

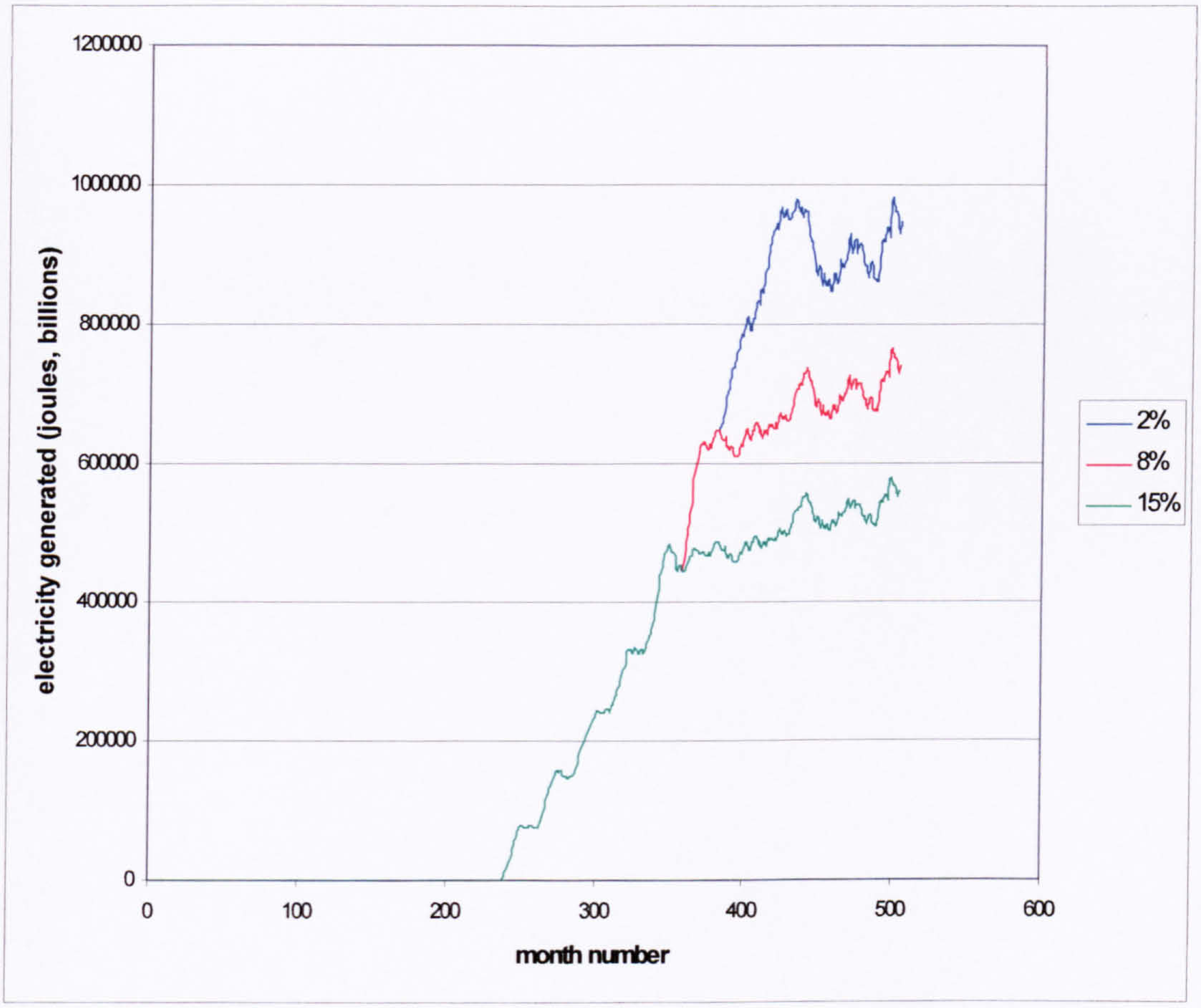

Figure 4-2. Electricity generated by wind power for the three tariff scenarios

Therefore, a scenario was built to determine the electricity generation from hydro technology based on changes to the variable "hydro installed". The values used, for the three scenarios, are shown in Table II-13 of Appendix II. The electricity generated by hydro power within the three scenarios is shown in Figure 4-3.

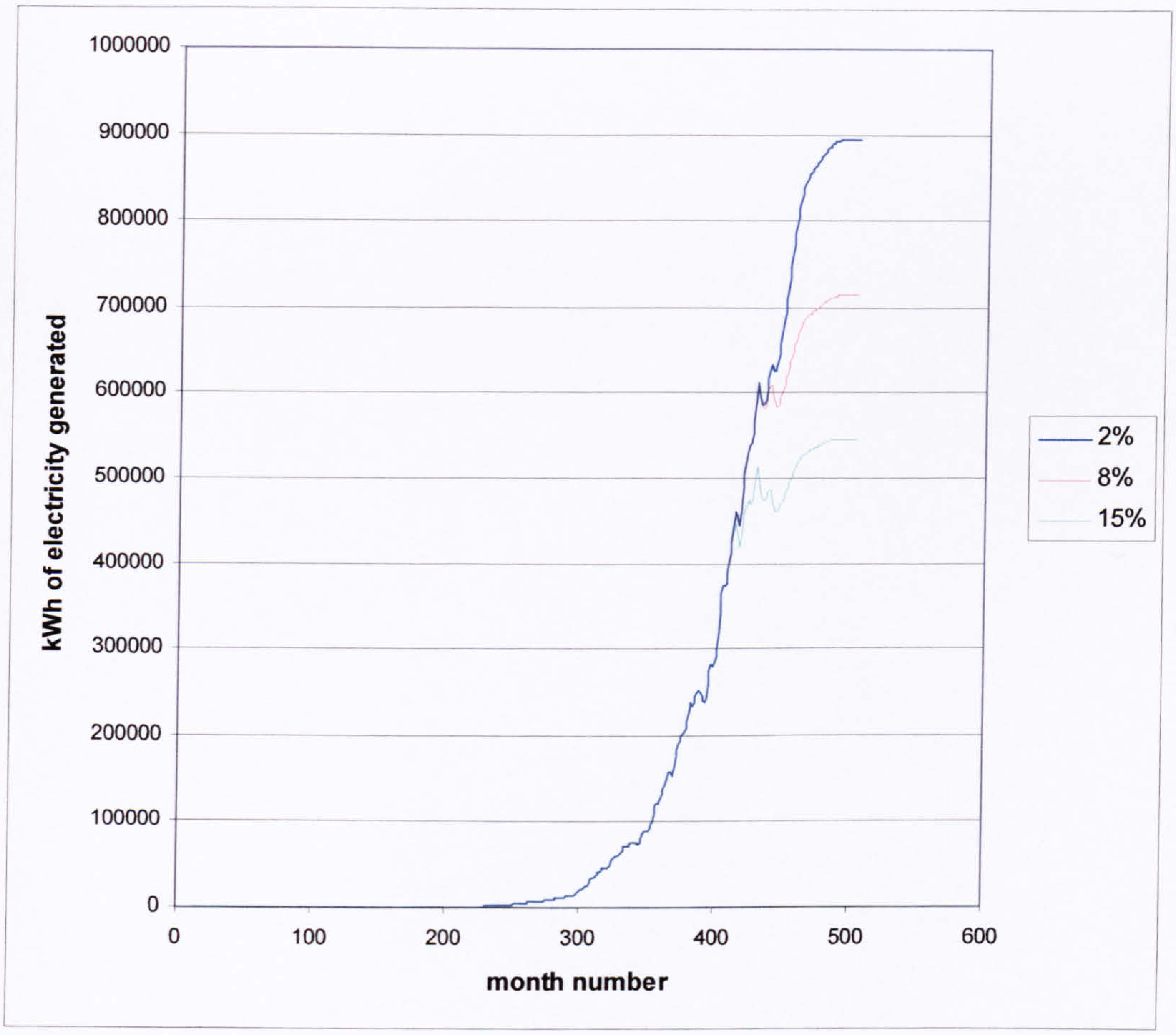

Figure 4-3. Electricity generated by hydro power for the three tariff scenarios

4.6.4 Photovoltaic

In order to develop three scenarios for photovoltaic generation (to meet electricity demand resulting from a two percent, eight percent and fifteen percent tariff) the same assumptions were made as for wind and hydro with regard to the earliest date for installation.

A scenario was built to determine the electricity generation from photovoltaic technology based on changes to the variable "pct s of houses with pv". This is the percentage of suitable houses with south facing roof area which are assumed to have photovoltaic panels installed. The values used, for the three scenarios, are shown in Table II-14 of

Appendix II. Note that, although the variable refers to the percentage of south facing houses with photovoltaics, the variable was actually used as a fraction and not a percentage.

The percentage of suitable south facing houses which had a photovoltaic panel gradually increased from zero (month 216) to one hundred percent (month 504). At a one hundred percent installation level the amount of electricity generated was not sufficient to meet all the demand for green electricity. The level of demand met from pv, for each tariff level, is shown in Table 4-2.

Table 4-2. Percentage of green electricity demand met by photovoltaics for the year 2025, for three tariff levels

	percentage demand met		
	2% tariff	**8% tariff**	**15% tariff**
month 504	30.3	38.5	51

The electricity generated by photovoltaics under the three scenarios is shown in Figure 4-4, although all scenarios are the same so only one line is shown.

4.6.5 Biomass

In order to develop three scenarios for biomass generation (to meet electricity demand resulting from a two percent, eight percent and fifteen percent tariff) the same assumptions were made as for wind and hydro with regard to the earliest date for installation.

In investigating scenarios for generation of electricity by biomass combined heat and power (CHP), an error in the model was found and corrected. The equation for the variable "bio CHP" was changed from:

bio CHP = CHP heat supply IF bio supply to CHP > CHP heat supply ELSE bio supply to CHP(4-4)

to:

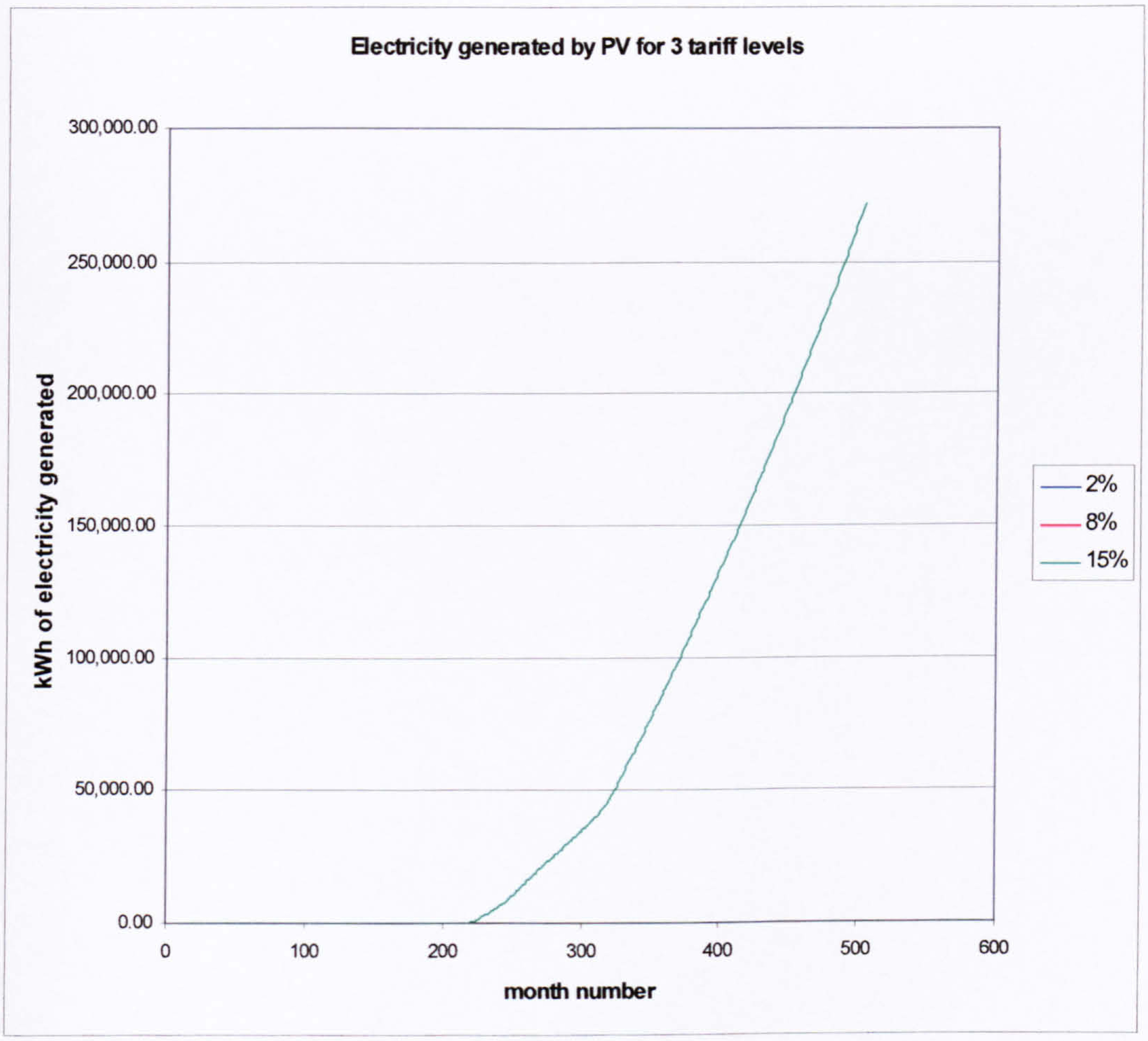

Figure 4-4. Electricity generated by photovoltaic power for the three tariff scenarios

$$\textbf{bio CHP} = \textbf{CHP heat supply x bio supply to CHP} \qquad \textbf{(4-5)}$$

A scenario was then built to determine the electricity generated from biomass technology, based on changes to the variables "bio supply to CHP" and "size of CHP available". The proportion of combined heat and power fuel which was biomass ("bio supply to CHP") was assumed to increase gradually from zero in month 216 (January 2002) to one hundred percent as shown in Table II-15 of Appendix II. The size of combined heat and power plant available was 2000 kW in month 216, based on existing combined heat and power installations in Leicester. The installation rate was assumed to gradually increase over time, as shown in Table II-16 of Appendix II.

The amount of electricity generated by biomass technology was limited by the market share of combined heat and power district heating for heating and hot water services. Once this limit was reached, increases in the variable "size of CHP available" had no effect on the level of renewable electricity generated. This upper limit to the level of biomass-generated electricity was relatively low, and for all three tariff premium scenarios the level of biomass electricity produced was below the level demanded.

Therefore, based on a business as usual scenario prediction for market penetration of CHP district heating, biomass electricity production in the DREAM model could not meet predicted demand for green tariff electricity. The level of demand achieved by biomass-generated electricity is shown in Table 4-3.

Table 4-3. The percentage of green electricity demand met by biomass for three tariff levels, in 2025

Tariff premium	Percentage of electricity demand from renewables	Percentage of renewable electricity demand met by biomass
2%	26.5%	21.8%
8%	20.8%	27.7%
15%	15.7%	36.7%

The level of electricity generated by biomass under the three scenarios is shown in Figure 4-5, although for each scenario the amount of electricity generated is the same so only one line is shown in the figure.

4.6.6 Equal contribution mix

In the market place it would be unlikely for one technology to completely dominate and deliver all green electricity demanded within a green tariff scenario. This would be particularly true for photovoltaic and biomass, which have been shown (in Section 4.6.4 and Section 4.6.5) in DREAM scenarios to have an upper limit to their generation potential.

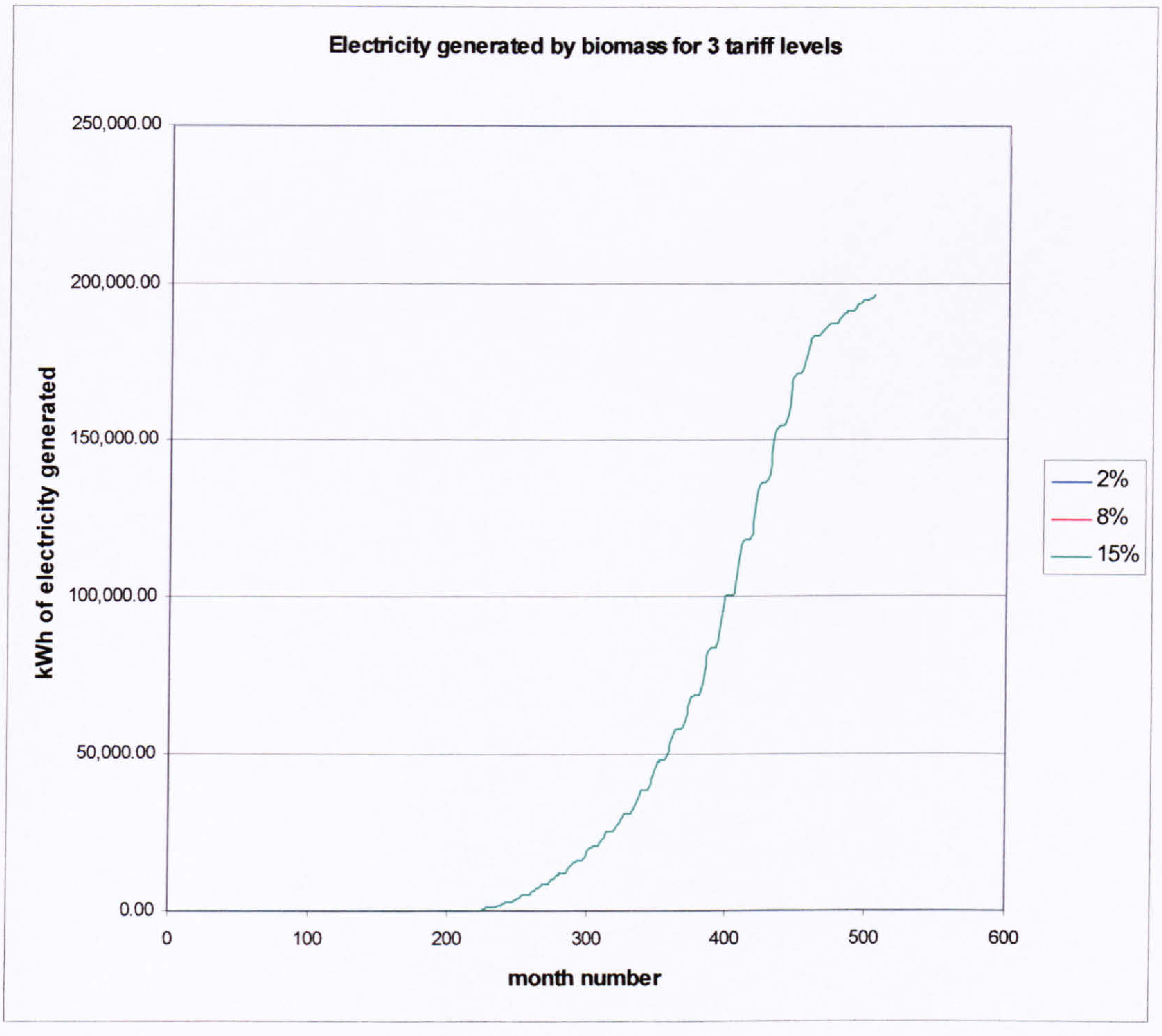

Figure 4-5. Electricity generated by biomass power for the three tariff scenarios

Therefore, a technology mix scenario was developed for each tariff level. For the eight percent and fifteen percent tariff scenarios it was assumed that the four technologies would each contribute equally to meet demand for green electricity. In the two percent tariff scenario the limits on generation by biomass (due to model assumptions regarding combined heat and power district heating market share) were such that biomass was only able to deliver on twenty two percent of green electricity demand. In this scenario, the remaining three technologies contributed equally to meet the remaining seventy eight percent demand, a contribution of twenty six percent each.

4.6.6.1 Two percent scenario

It was assumed that the wind turbine diameter would be 68m, as in Section 4.6.2. It was assumed, for all technologies, that no new installation could occur prior to month 216. It was assumed that the installation rate would gradually increase over time. The level of electricity generated by the four technologies is shown in Figure 4-6. The level of technology installed, for all four technology types, is shown in Appendix II, Table II-17 to Table II-21.

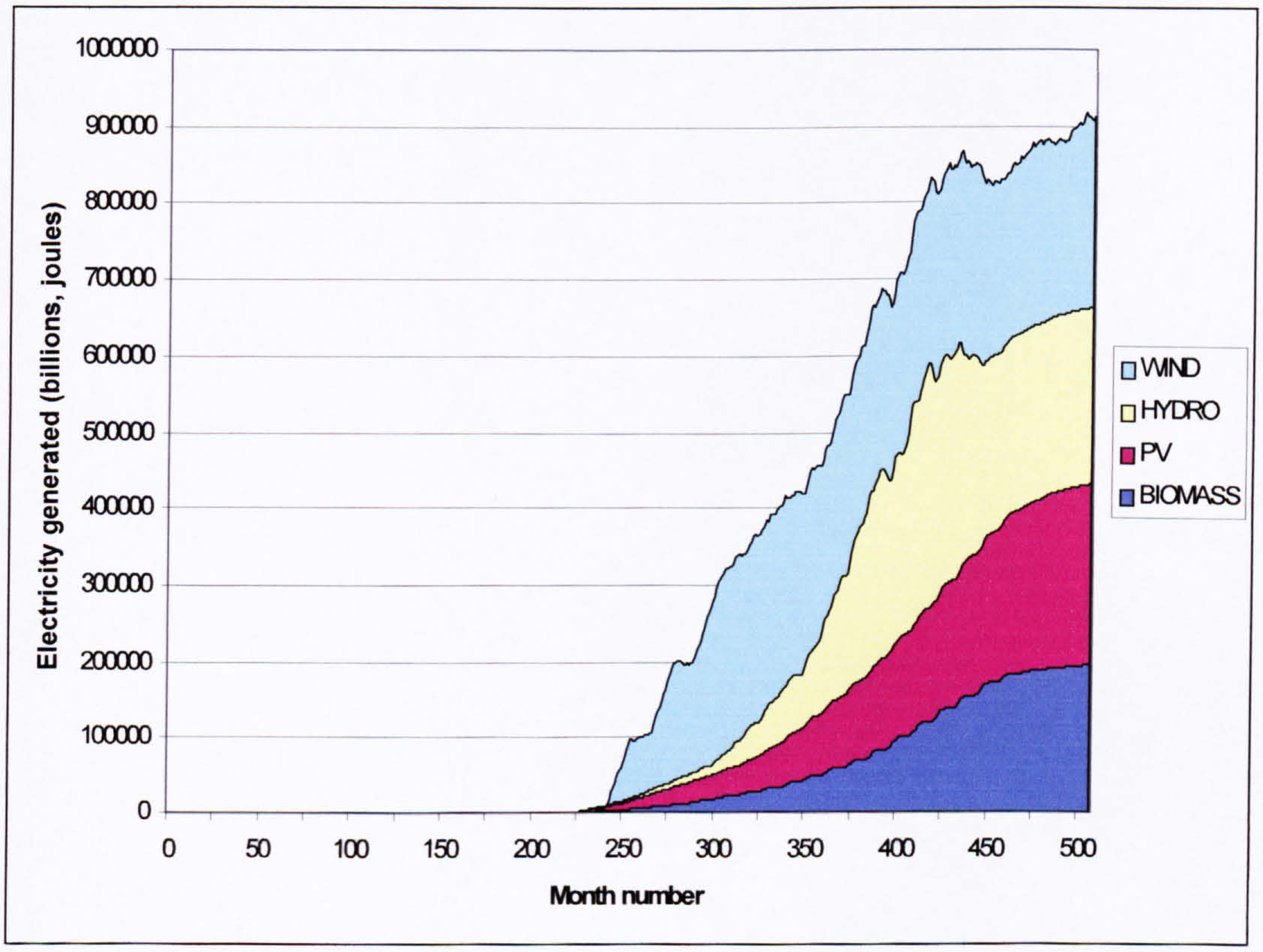

Figure 4-6. Electricity generated by all four technologies for the two percent equal contribution tariff scenario

4.6.6.2 Eight percent scenario

The same assumptions were made for this scenario as for the equal contribution technology mix two percent tariff. The level of electricity generated by the four technologies is shown in Figure 4-7. The level of technology installed, for all four technology types, is shown in Appendix II, Table II-22 to Table II-26.

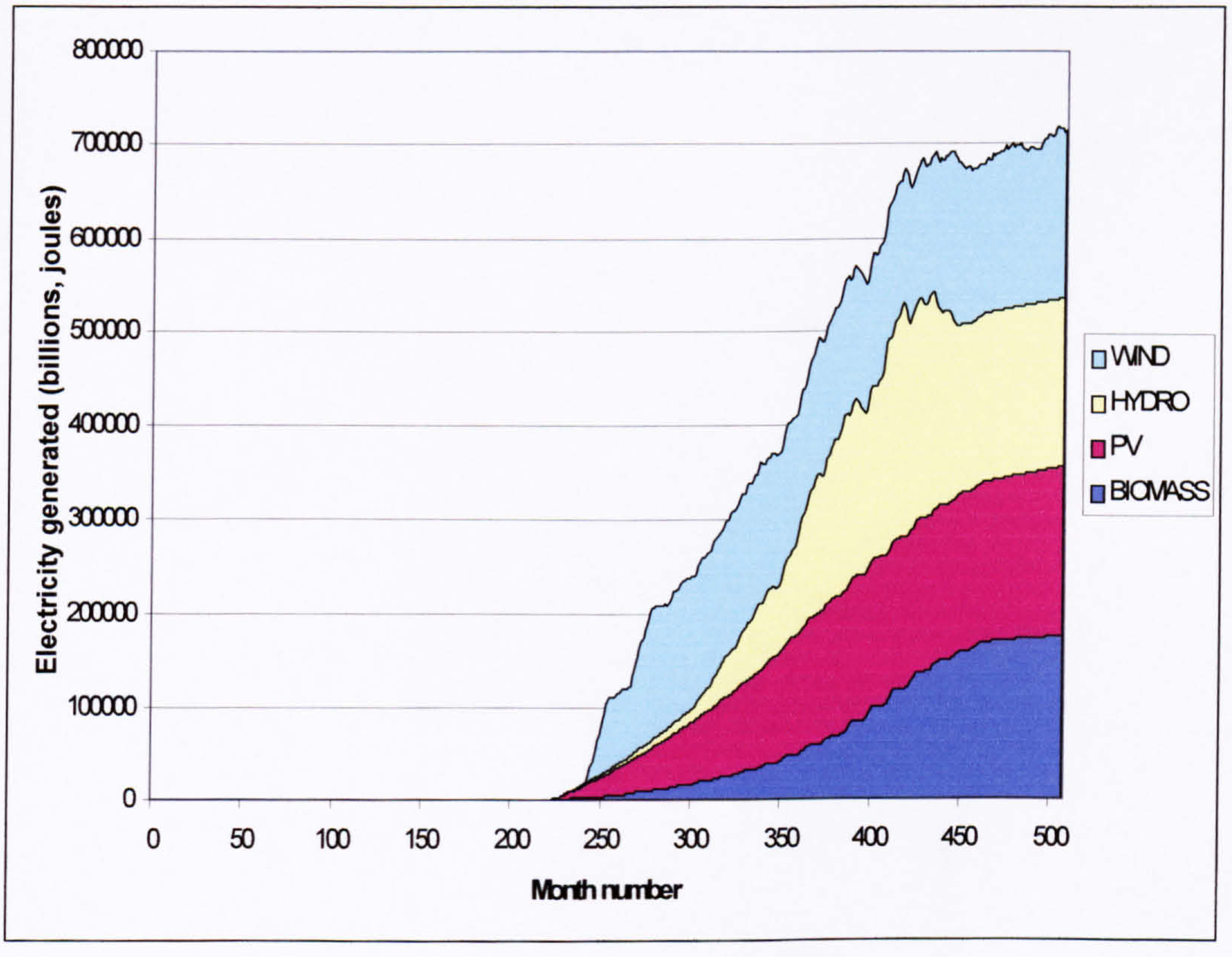

Figure 4-7. Electricity generated by all four technologies for the eight percent equal contribution tariff scenario

4.6.6.3 Fifteen percent scenario

The same assumptions were made for this scenario as for the equal contribution technology mix two percent tariff. The level of electricity generated by the four technologies is shown in Figure 4-8. The level of technology installed, for all four technology types, is shown in Appendix II, Table II-27 to Table II-31.

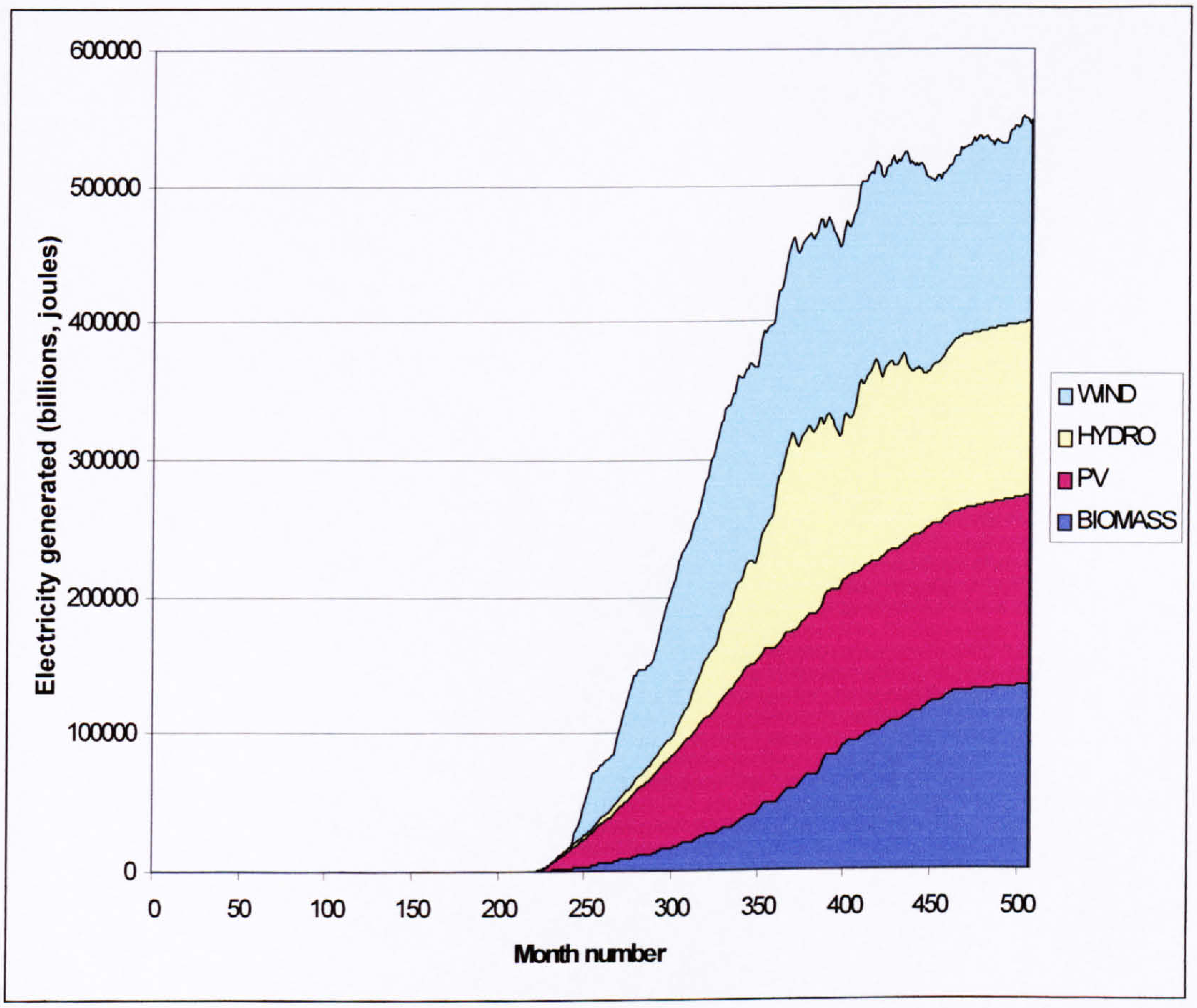

Figure 4-8. Electricity generated by all four technologies for the fifteen percent equal contribution tariff scenario

4.6.7 Scenarios incorporating gradual uptake of green tariff options

The scenario work presented in Section 4.6.2 to Section 4.6.6 assumed that green tariff uptake could be predicted based entirely on results of the willingness to pay survey and Equation 3-2 on page 83. However, as discussed in Chapter 3, the contingent valuation method was not ideal and the actual level of participation had not yet reached the levels of stated willingness to pay in the United States. Byrnes, Rahimzadeh, Baugh and Jones (1995) estimated that between twelve and fifteen percent of those who said they were willing to pay actually paid a premium when given the opportunity. The actual market for green power in the United Kingdom was immature in 2002, with little consumer awareness of renewable electricity, low levels of marketing and shifting policy incentives. It therefore seemed more appropriate to consider the willingness to pay results as an indication of the potential market penetration of green power products in the later stages of the product life-cycle.

A product passes through various life-cycle stages: product development; growth; maturity; and decline. Market penetration varies throughout these stages and typically follows a standard "S" curve.

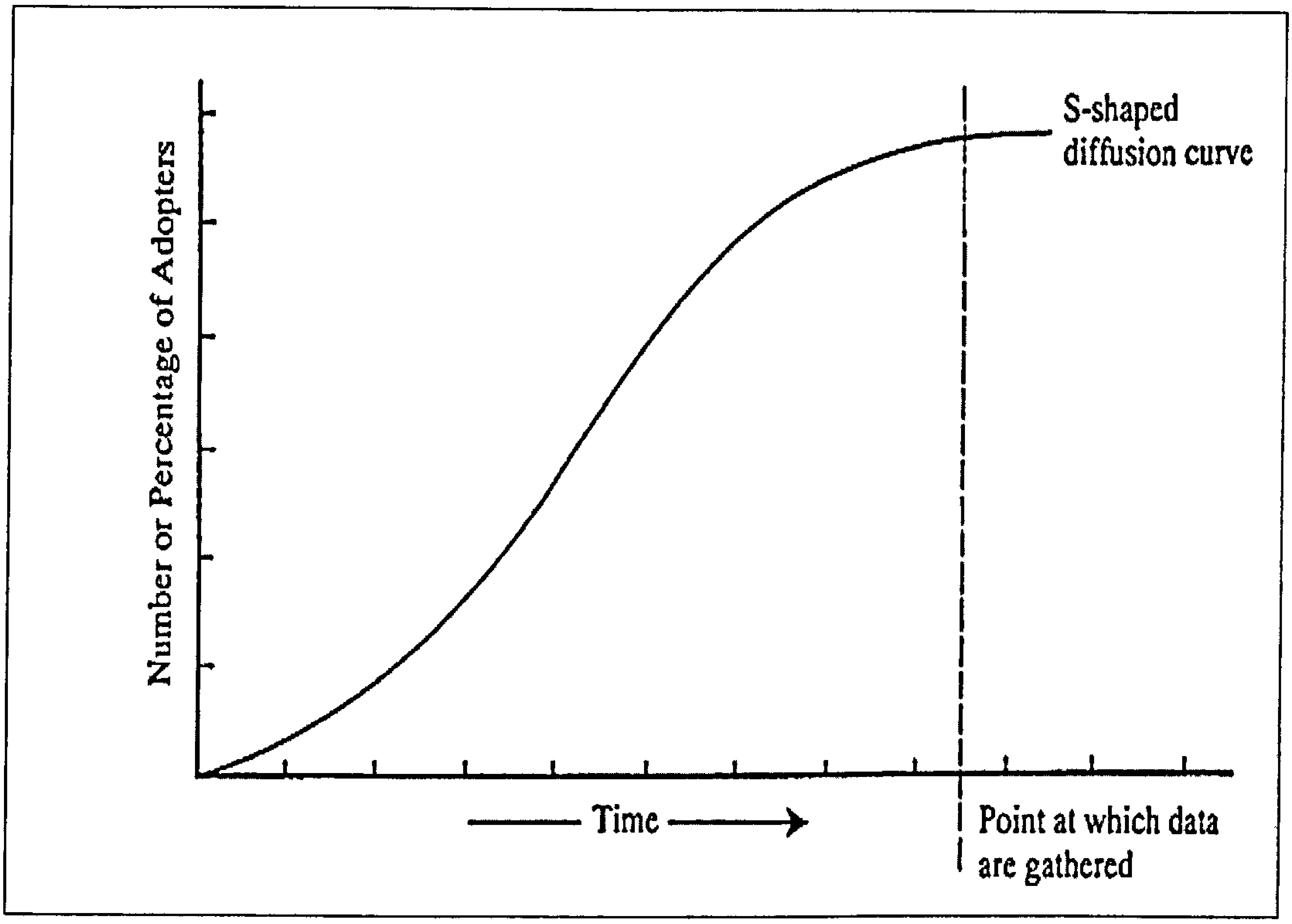

Figure 4-9. S-shaped diffusion curve (Rogers, 1995)

This theory, and experience of other deregulated utility markets and green products, enabled Wiser, Bolinger, Holt and Swezey (2001) to forecast the growth of green power markets in the United States. They noted that it took competitors some time to capture market share from dominant monopolies, that there was a length of time between market introduction and market response for new products, that public policy could have a significant impact on market penetration of green products, and that indicators of general environmental attitudes were consistent with uptake of some green products. Based on the "S" curve of product life-cycle, Wiser, Bolinger, Holt and Swezey (2001) modelled total renewable generation capacity supported by green power marketing in a high growth and low growth scenario.

The same principles were applied to this research, in order to predict green tariff uptake over time. In the previous scenarios, uptake had been assumed to be equal to willingness to pay from month zero. This was an unrealistic assumption, given that it assumed a 26.45 percent, 20.81 percent, or 15.72 percent uptake of green tariffs (for a two percent, eight percent, or fifteen percent premium) in December 2001. Uptake in December 2001, estimated below, was actually of the region of 0.19 percent.

In order to model predicted uptake of green tariffs over time, several assumptions were made. It was assumed that the "S" curve could be described by three phases. The first stage was a low rate of uptake, the second a high rate of uptake, and the third stage was low rate of uptake.

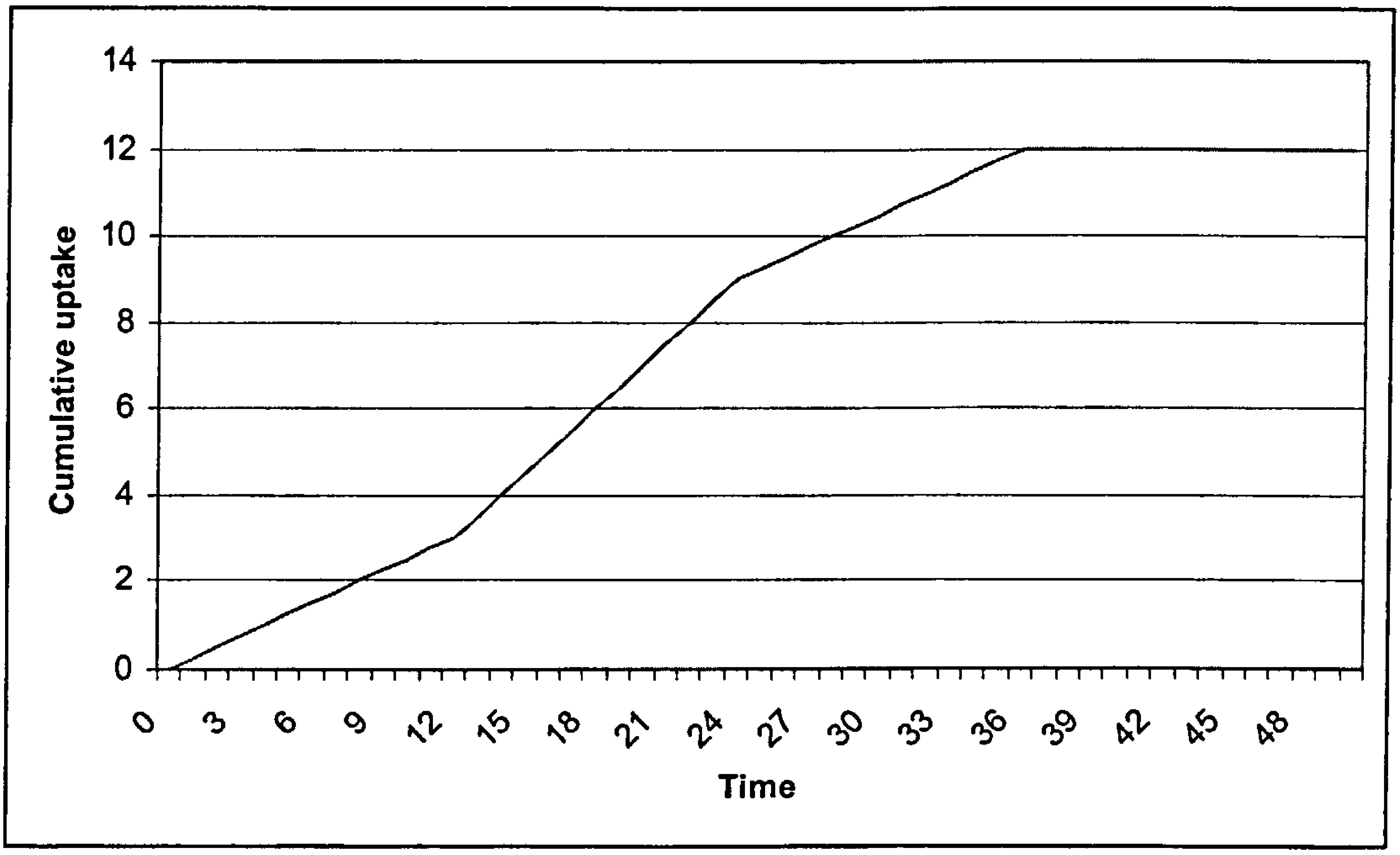

Figure 4-10. Approximation of the "S" curve - three stages to maximum market penetration

It was assumed that the willingness to pay results represented an absolute maximum market penetration possible for green electricity tariffs. It was assumed that, in 1998/9, the market penetration at the date of liberalisation was zero. It was assumed that, by December 2001, the market penetration of green electricity tariffs was 0.19 percent. This market share was based on 45,150 known green electricity customers in the United Kingdom in December 2001 (GreenPrices, 2002) and 23,800,000 total electricity customers in the United Kingdom in June 2001 (Office of Gas and Electricity Markets, 2001), and was achieved over four years of domestic competition. The model assumed that the annual demand for electricity for each year was the January value of annual rolling electricity demand under the DREAM Business as Usual scenario. Market penetration was modelled from 2002 to 2025, with the year zero (2002) penetration assumed to equal 0.19 percent.

Two market penetration models were developed, a low-growth and high-growth scenario. For each, assumptions were made based on the length of each phase and the rates of market penetration in each phase. At year zero (2002), up to four years of the first phase of market penetration had passed (1998 to 2001). The assumptions for each stage, for the low and high growth models, are shown in Table 4-4.

Table 4-4. Assumptions made in the low growth and high growth green tariff uptake models

	Phase 1		Phase 2		Phase 3	
	length	rate of uptake	length	rate of uptake	length	rate of uptake
Low	8 years	0.25	12 years	0.5	12 years	0.25
High	3 years	0.5	7 years	1	7 years	0.5

It was assumed that each annual growth in demand would have a default green tariff uptake equal to year zero. This assumption was also made by Wiser, Bolinger, Holt and Swezey (2001) for their predictions of United States green tariff uptake and was a conservative assumption that new load entering the market should be treated as if entering the market at year zero. The length of phase one in the model was shorter than subsequent phases to account for the fact that phase one actually started in 1988/9, and not 2002. The assumed values for the length and product penetration growth rate of the stages was based on the product life-cycle of other green products (Wiser, Bolinger, Holt and Swezey, 2001), and green tariff experience in the United States and United Kingdom. As a result of the two models, figures for total green electricity demand were obtained for the years 2002 to 2025. These results are shown in Appendix II, with green electricity demand shown in Figure 4-11 and the percentage domestic market penetration shown in Figure 4-12. The green electricity demand was used to formulate two further DREAM scenarios. In each scenario, the demand for green electricity was met by all four technologies modelled within DREAM, and each made an equal contribution. The two DREAM scenarios showed the level of renewable energy generation plant required to meet green electricity demand for the high growth and low-growth market penetration models. The level of technology plant required to meet the two scenarios is shown in Section II.2.5 and Section II.2.6 of Appendix II. Figure 4-13 and Figure 4-14 show the amount of electricity generated by the four technologies in both the high growth and low growth DREAM scenarios.

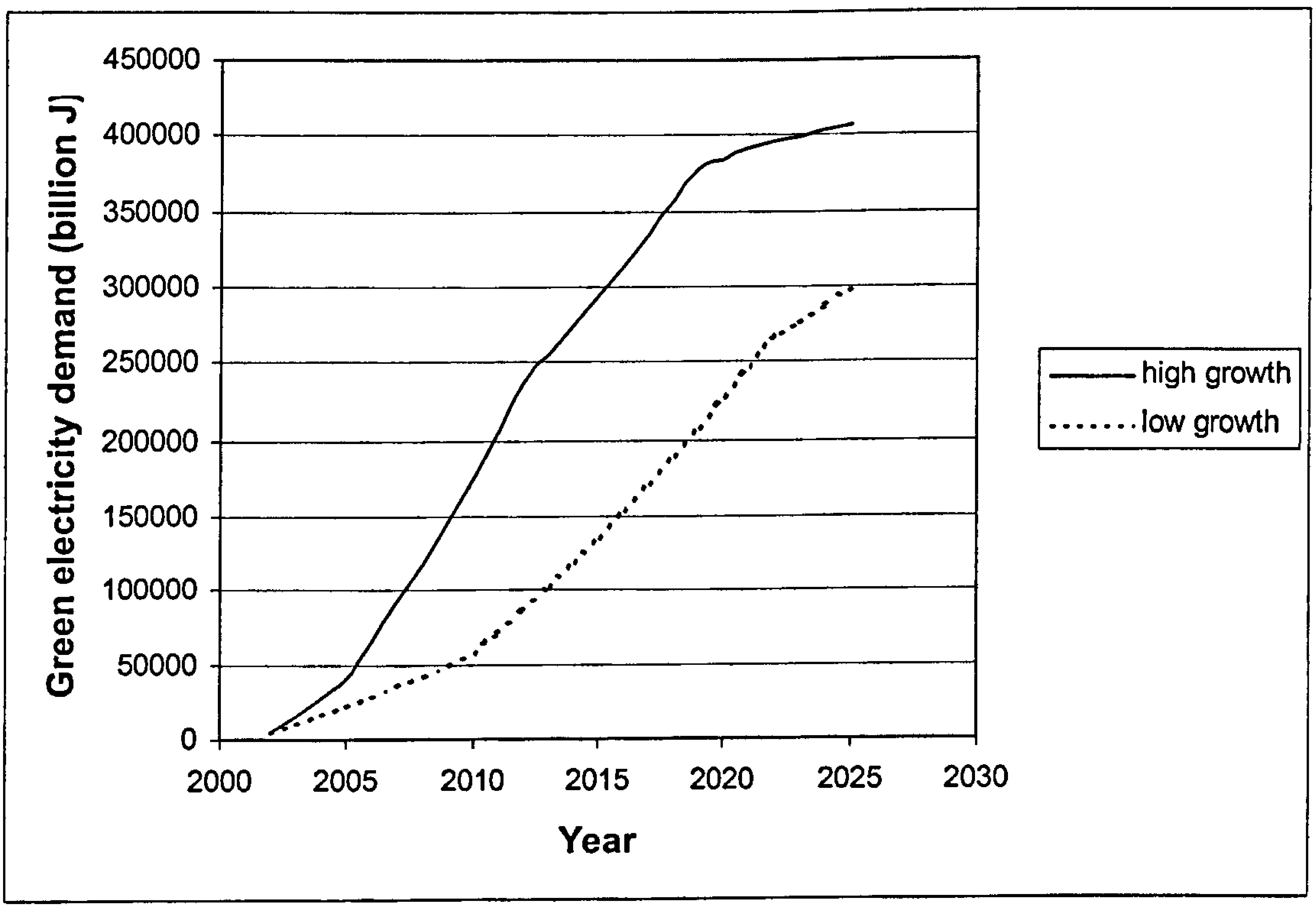

Figure 4-11. Green electricity demand for the high and low growth scenarios

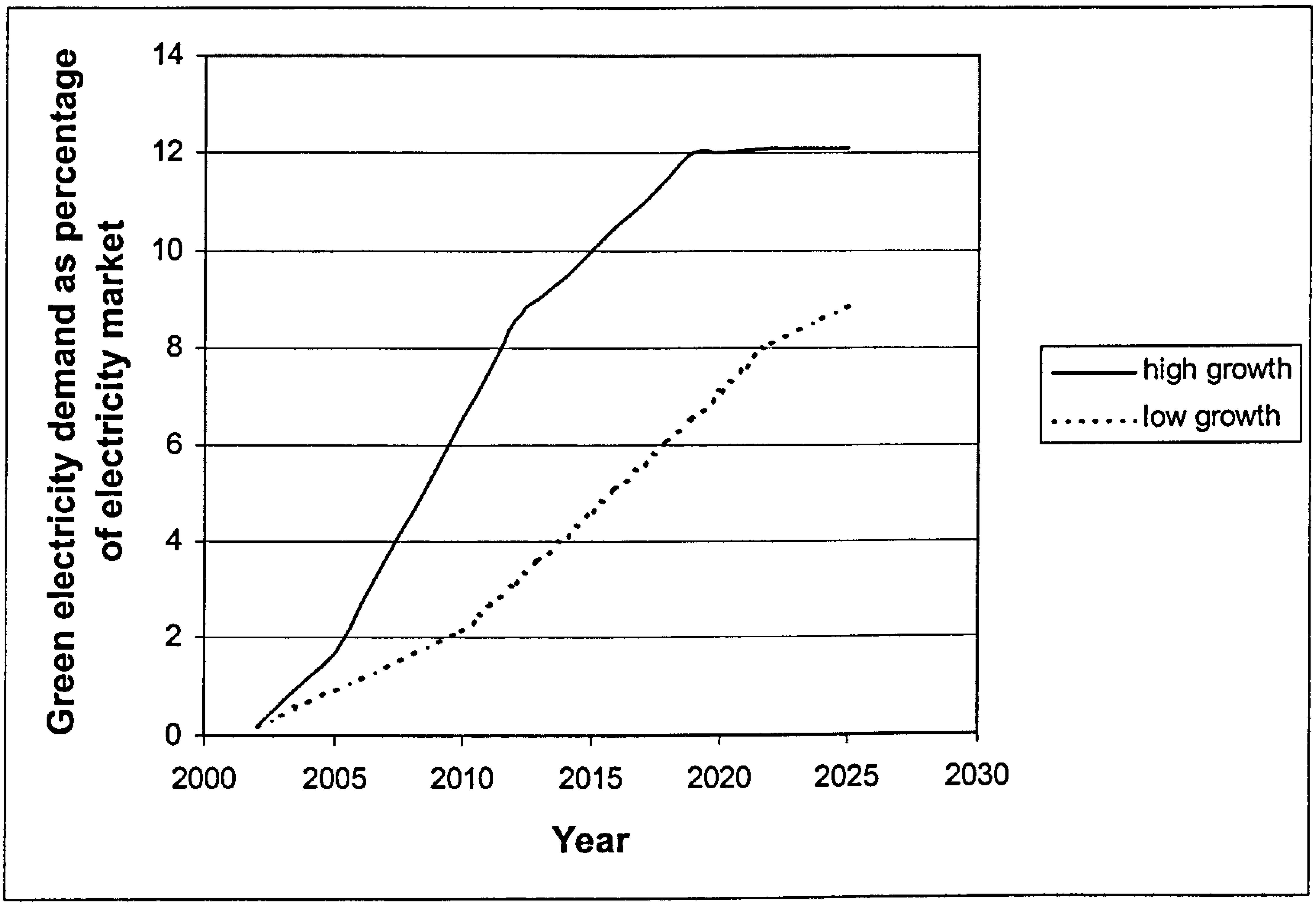

Figure 4-12. Green electricity demand as a percentage of domestic electricity market share, for the high and low growth scenarios

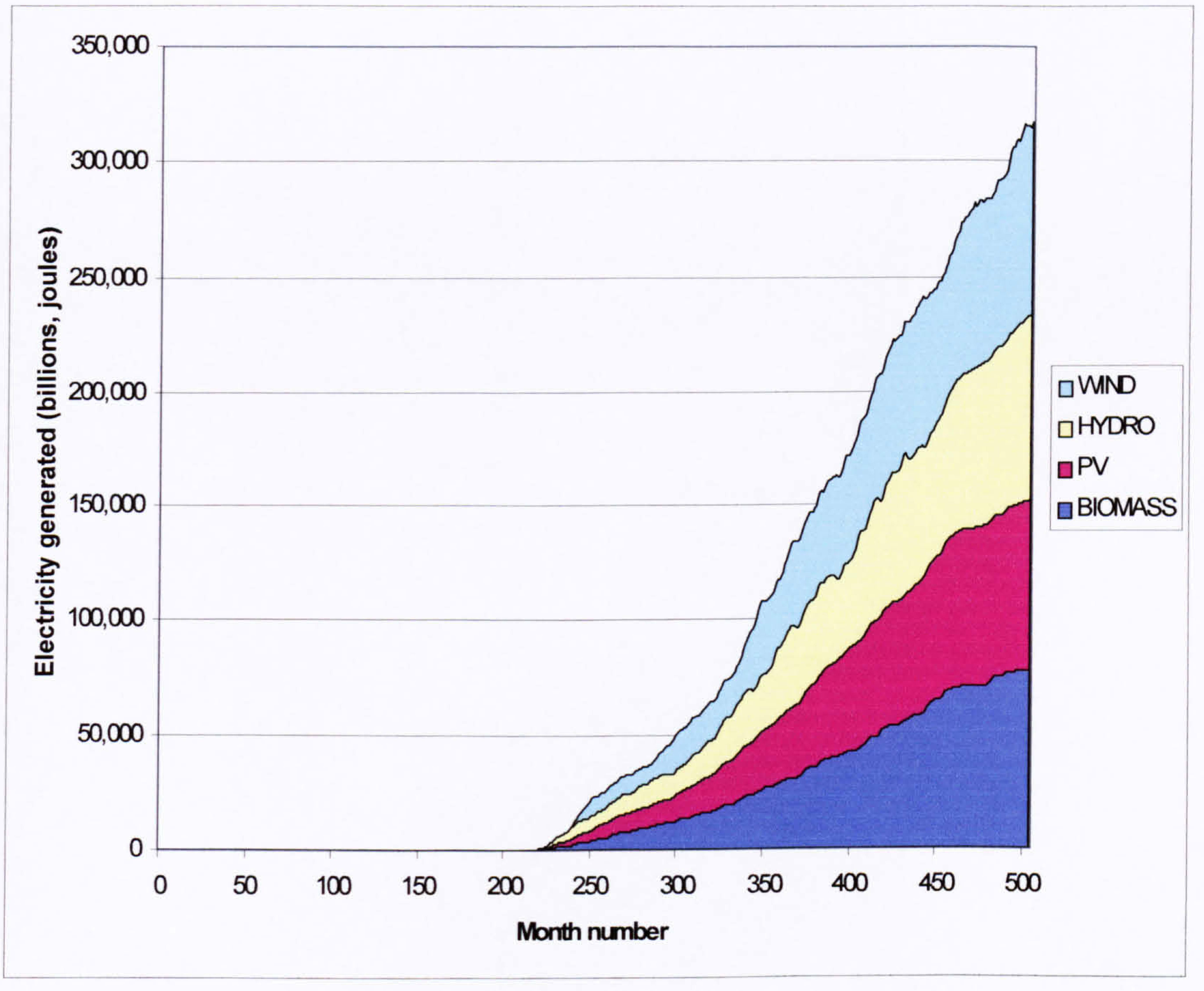

Figure 4-13. Green electricity generated by four technologies in the low growth DREAM scenario

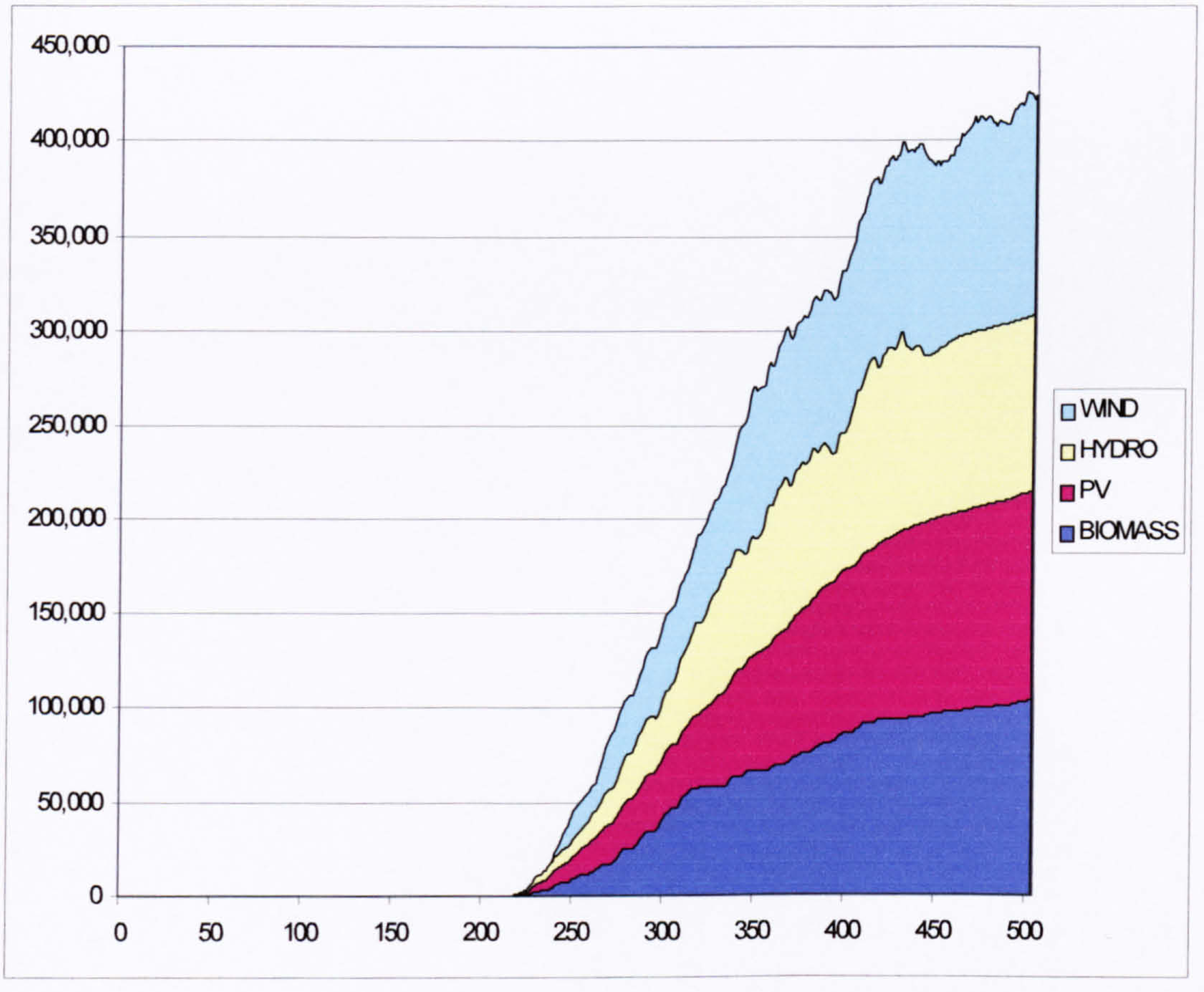

Figure 4-14. Green electricity generated by four technologies in the high growth DREAM scenario

4.7 Summary

Following a review of available domestic energy models, the Dynamic Regional Energy and Emissions Assessment Model (DREAM) was chosen and a sensitivity analysis was completed. The model outputs were most sensitive to changes to the input variables floor area, internal temperature, heat loss parameter, number of people per household and number of residents. Changes to these variables resulted in linear changes in output variables, and changes to combinations of input variables resulted in approximately the same change in output variables as the sum of each individual's effect on output variables.

Assuming uptake of green tariffs could be predicted by the willingness to pay equation $Y = 100e^{(-0.04)M - 1.25}$, future (to 2025) demand for green electricity was modelled within DREAM for four different technology scenarios and a technology mix, for three different tariff levels.

Assuming uptake of green tariffs could instead be better predicted by the standard "S" curve of market diffusion, and that willingness to pay results better represented a maximum market penetration of green electricity tariffs, two further technology mix scenarios were developed for high and low growth market uptake.

Results indicated that photovoltaic and biomass were not able to meet green tariff demand on their own within the DREAM model, assuming green tariff uptake equalled the willingness to pay results. Under the low growth and high growth scenarios the demand for green electricity reached 8.87 percent and 12.09 percent respectively of total electricity demand in 2025.

Chapter 5: Meeting demand – a case study resource estimate

5.1 Introduction

A case study resource estimate follows. It looks at a district of Nottinghamshire and attempts to relate the renewable energy resource to predicted renewable energy demand (as a result of green tariff offerings) as defined in the previous two chapters.

Newark and Sherwood district was chosen as the case study area. This was for two reasons. Firstly, at the time there had been national and county level resource assessments, but no assessment at the district level. And secondly, the District Council had committed to ensuring savings of twenty percent of carbon dioxide emissions below 1990 levels by 2010 in response to Government climate change targets, and were supportive of the concept of a renewable energy resource assessment for the district as a supporting tool for that carbon dioxide reduction policy.

5.2 The case study area

Newark and Sherwood is a largely rural district embracing the heart of the legendary Sherwood Forest in North Nottinghamshire. The district comprises a land area of 650 km^2 and has a total population of 104,200 living in 43,563 dwellings. There are three main centres to the district. Newark has a rich heritage of buildings and archaeological remains from various periods of British history. It acts as a main shopping centre for the surrounding rural population and is also a tourist centre for the district. Southwell is six miles west of Newark, and is a small country town of outstanding architectural and historic interest. At the heart of the town stands Southwell Minster, surrounded by predominantly Georgian buildings in what has been designated a Conservation Area. Ollerton is situated to the north west of the district and is close to Sherwood Forest Country Park, Rufford Country Park and Center Parcs holiday centre. This area of the district has been associated with the coal mining industry for some time, an industry which is in sharp decline.

The Newark and Sherwood District Council has been an advocate of energy efficiency for many years. Several areas have been targeted for housing improvement schemes, carbon dioxide reduction targets and strategies, and sustainable industrial and residential development. The area also has an European funded Energy Agency.

The district had already investigated the energy use in the area and published findings in "An Energy Strategy for Newark and Sherwood District" (Newark and Sherwood Energy Agency, 1998). This report recommended that an investigation into the renewable energy resources in the area be carried out. This resulted in a report, presented to Newark and Sherwood Energy Agency, "Renewable Energy Balance Plan" (Newark and Sherwood Energy Agency, 1999).

5.3 Renewable resources

Due to their very nature, renewable sources of energy are generally dispersed over an area of lower density than traditional fossil fuels. The development of these dispersed resources is, however, highly desirable, for several reasons. The burning of fossil fuels results in pollution, of which carbon dioxide is of greatest concern (being a greenhouse gas) due to its contribution to climate change. If replacing some fossil fuel use with renewable energy, the overall level of greenhouse gas emissions can be reduced. Climate change is just one aspect of the pollution associated with energy use. As energy-related pollution is reduced quality of life is improved and the local environment is enhanced.

Fossil fuels are a finite resource, and will eventually be depleted. Whilst there was continuous new discovery of gas, coal and oil reserves, North Sea fossil fuel reserves were predicted to be depleted within the medium term and by 2020 the UK was expected to be predominantly dependent on energy imports (Performance and Innovation Unit, 2002). Higher levels of energy import were seen as a potential future risk to security of supply. By using local dispersed renewable resources, it may be possible to slow the depletion of UK fossil fuel stock and replace it directly with a local energy supply. A switch to renewable sources of energy would also benefit the economy. Reduced import of fossil fuels would improve security of supply and the balance of payments. Research into the employment implications of more sustainable energy use indicated that there would be a net job gain by reducing the amount of electricity generated from fossil fuels and increasing the contribution made by renewable energy (Ecotec, 1995). The potential world market for renewable energy products is large. By gaining experience in, and developing the technology for, renewable energy a country or district can capture a share of that export market and prosper.

Carbon dioxide emissions have a significant effect on climate change. Recent international agreements on greenhouse gas levels, made at Rio and Kyoto, have set significant targets to reduce carbon dioxide emissions, with UK Government also setting a domestic target for CO_2 reduction (Department of Environment, Transport and the

Regions, 2000). These targets were being discussed at the national and regional level, to ensure that national targets could be delivered through the devolvement of responsibility for action to the regions, and hence to local authorities.

In order to meet ambitious targets for greenhouse gas emissions reduction, there may be a rapid move towards using:

- fossil fuels with a low carbon to hydrogen ratio (for example, natural gas);
- renewable energy systems which produce no carbon dioxide emissions;
- high efficiency heat, hot water and electricity generation systems, which convert fossil fuels to useful energy with the minimum level of carbon dioxide emissions;
- alternative fuel sources (hydrogen, biomass oils, etc.) which will be developed to reduce the global impact of carbon dioxide emissions.

5.3.1 The renewables technologies considered

Only those technologies suitable for the generation of electricity were incorporated into this renewable resource assessment.

- Wind.
- Photovoltaic.
- Hydro-electricity.
- Biomass.
- Landfill gas.

5.4 The potential renewable electricity resource in Newark and Sherwood

This research had, so far, considered the potential for green tariffs to increase the demand for renewable sources of electricity. Therefore, this analysis of the renewable resource in Newark and Sherwood only dealt with resources that generated electricity, and could therefore contribute to a green tariff scheme. Full details of the thermal energy output from the renewable energy resource in Newark and Sherwood was reported in "Renewable Energy Balance Plan" (Newark and Sherwood Energy Agency, 1999). For electricity generation purposes, electricity from combined heat and power units was included in this analysis.

In each technology band, an estimate was made of the total resource and the practicable resource. The maximum resource represents the total power which existed in the resource, limited only by the technology used to extract that power. The practicable resource took into account further constraints, such as economic viability and conflicting land use requirements, to determine what power could feasibly be generated from a resource. The assumptions made in calculating the total resource and the practicable resource were, wherever appropriate, identical to those assumptions made in resource assessments for the East Midlands region (Duffin, 1998; Land Use Consultants and IT Power, 2001). This then enabled appropriate comparison to be made between estimates of the renewable energy potential in Newark and Sherwood, in the county of Nottingham and in the region of the East Midlands.

5.4.1 Wind

An estimate of the wind resource for Newark and Sherwood was possible through the use of the NOABL database.

Initially, the Ordinance Survey grid references into which Newark and Sherwood fell were identified using standard Ordinance Survey maps (Ordinance Survey, 1997; Ordinance Survey, 1997a; Ordinance Survey, 1998). This identified a rectangle of 1km^2 squares covering 456000-490000 Easting and 340000-375000 Northing (1,225 km^2). Boundary data information was then downloaded from UKBORDERS (UKBORDERS, no date) geographical information service on EDINA (a national data centre based at Edinburgh University Data Library).

The Department of Trade and Industry NOABL database of estimated annual average wind speeds was then downloaded (Department of Trade and Industry, no date). This wind speed database contained estimates of the annual mean wind speed throughout the UK. The data was the result of an air-flow model that estimated the effect of topography on wind speed. There was no allowance for the effect of local thermally driven winds such as sea breezes or mountain/valley breezes. The model was applied with 1km square resolution and made no allowance for topography on a small scale or local surface roughness (such as tall crops, stone walls, or trees), both of which may have a considerable effect on the wind speed. Wind data for heights 10m, 25m and 45m were extracted from NOABL for the rectangle of Ordinance Survey co-ordinates for Newark and Sherwood district.

This data input table was exported into MapInfo, overlaid with the digitised boundary data, and data points were interpolated to provide a wind speed contour map. The image produced is displayed as Figure 5-1. It shows estimated wind speed values for a height of 10m above ground.

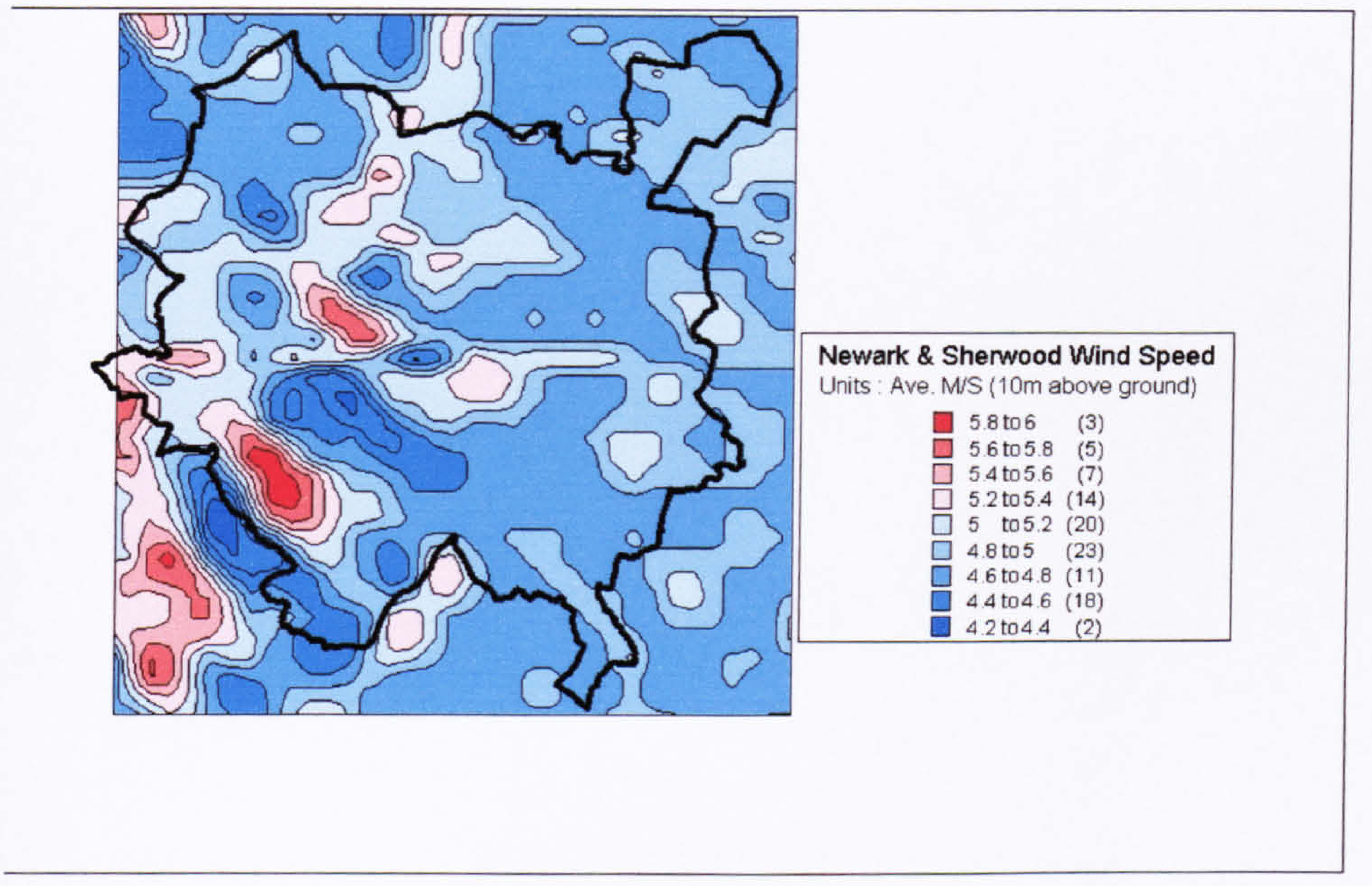

Figure 5-1. Annual average wind speeds at 10m above ground, for Newark and Sherwood

5.4.1.1 Total resource

The annual electricity production at a site may be estimated using the equation

$$E = K \cdot (V_m)^3 \cdot A_t \cdot T \tag{5-1}$$

(Boyle, 1996).

E = annual electricity production, kWh.

K = factor based on typical performance characteristics, ninety percent availability, five percent array shadow losses, and an approximate relationship between mean wind speed and wind speed frequency distribution.

V_m = annual mean wind speed.

A_t = swept area of turbine.

T = number of turbines.

This formula was used to calculate the annual electricity production at a site. This was based on the annual mean wind speed (V_m) data from the NOABL database, for a height of 45m above ground. K=2.5 based on typical turbine performance characteristics.

The practicable resource potential was estimated using two sizes of turbines - a 225kW 27m VESTAS and a 600kW 42m VESTAS. The smaller turbine was likely to appeal to the individual farm or small developer, whilst the larger turbine was more likely to be used as part of a wind farm development by a large renewable energy developer. Annual electricity production data for these two machines was provided by the manufacturer. However, this technical data produced annual electricity production values typically fifty percent higher than those calculated using the theoretical equation. The theoretical equation was used in all energy estimates, and may therefore have underestimated turbine performance.

One square kilometre of empty land could contain at least nine turbines, at suitable separation distances (ten blade diameters (Department of Environment, 1993)) to avoid array losses. The NOABL data provided an estimated annual wind speed for each square kilometre. Excluding those one kilometre squares which were predominately outside the Newark and Sherwood boundary resulted in an area for analysis of 646 km^2. The total resource within this 646 km^2 was 5,034 GWh/y, based on nine turbines per square kilometre, 600 kW size. For this estimate, the predicted turbine output was calculated for each separate square kilometre using the wind speed data. Assuming an installation density of 9 MW/km^2 (Land Use Consultants and IT Power, 2001) then this would equate to an installed capacity of 581 MW.

5.4.1.2 The practicable resource

A visual examination of Ordinance Survey maps of the district showed that 94 km^2 squares were more than fifty percent (by area) built up, parkland, woodland, water or road. These areas were therefore assumed unavailable for wind energy development, leaving 552 km^2 potential land area for wind development. More detailed analysis of Ordinance

Survey information may have allowed a resource estimate based on development recommendations of 350 to 400 metres minimum distance of turbines from dwellings (Department of the Environment, 1993; British Wind Energy Association, 1994), but this was not deemed necessary for the resource assessment at this stage.

Three practicable resource analyses were completed. In the first instance, only areas with wind speeds of 6.8 metres per second or greater were assumed available for the erection of a wind turbine. Seven prime wind speed sites were identified in Newark and Sherwood. These 1 km^2 sites all had annual average wind speeds above 6.8 metres per second. Output from a cluster of nine large turbines (600 kW), from a single large turbine (600 kW), and from a single small turbine (225 kW), was estimated for each site.

In the second analysis, areas of 6.6 metres per second or more annual average wind speed were included for wind development. Twenty three prime sites were identified with wind speeds above 6.6 metres per second and for each site the output from a single large (600kW) or small (225kW) turbine was estimated. In this second analysis it was assumed that the wind development would involve a single turbine, placed no less than two kilometres from any neighbouring turbine.

Assuming that some of the prime sites would be sensitive to wind development, one final resource estimate was carried out. In this instance it was assumed that twenty five wind turbines would be installed in the district, at sites with average annual wind speed equal to the district average (6.3 metres per second). These turbines could be installed as single machines, or in clusters.

The results are shown in Table 5-1. Figure 5-2 shows the three categories of wind speeds on a grid map of Newark and Sherwood. Excluded areas are white, and the shades of blue are areas with a wind speed greater than or equal to the district average of 6.3 ms^{-1}.

Table 5-1. Electricity generation potential for wind turbines in Newark and Sherwood

Annual average windspeed (metres per second)	**Number of wind turbines**	**225 kW Vestas machine, 27 metres diameter**			**600 kW Vestas machine, 42 metres diameter**		
		Potential annual electricity generated (MWh)	Number of households served*	% of Newark & Sherwood households served	Potential annual electricity generated(MWh)	Number of households served*	% of Newark & Sherwood households served
Greater than or equal to 6.8	7 63 in clusters	3,294	784	1.80%	7,974 71,766	1,899 17,087	4.36% 39.22%
Greater than or equal to 6.6	23	10,038	2,390	5.49%	24,279	5,780	13.27%
Newark and Sherwood average - 6.3	25	8,950	2,131	4.89%	21,650	5,155	11.83%

*The number of households served is the number of households whose electricity demand can be met entirely by the technology concerned. This is based on a UK annual average domestic electricity consumption of 4.2 MWh, derived from information contained in the *"Digest of United Kingdom Energy Statistics 1996"* (Department of Trade and Industry, 1996).

5.4.1.3 Development implications

The windiest parts of Newark and Sherwood district were to the west, and therefore turbines sited purely for wind speed considerations would be some distance from the largest load centre of Newark.

Clearly, wind speed would not be the only consideration when determining the location of a wind turbine. The current land use, land ownership, local electricity demand, access to the distribution network and site access would be just some of the major considerations when choosing a site.

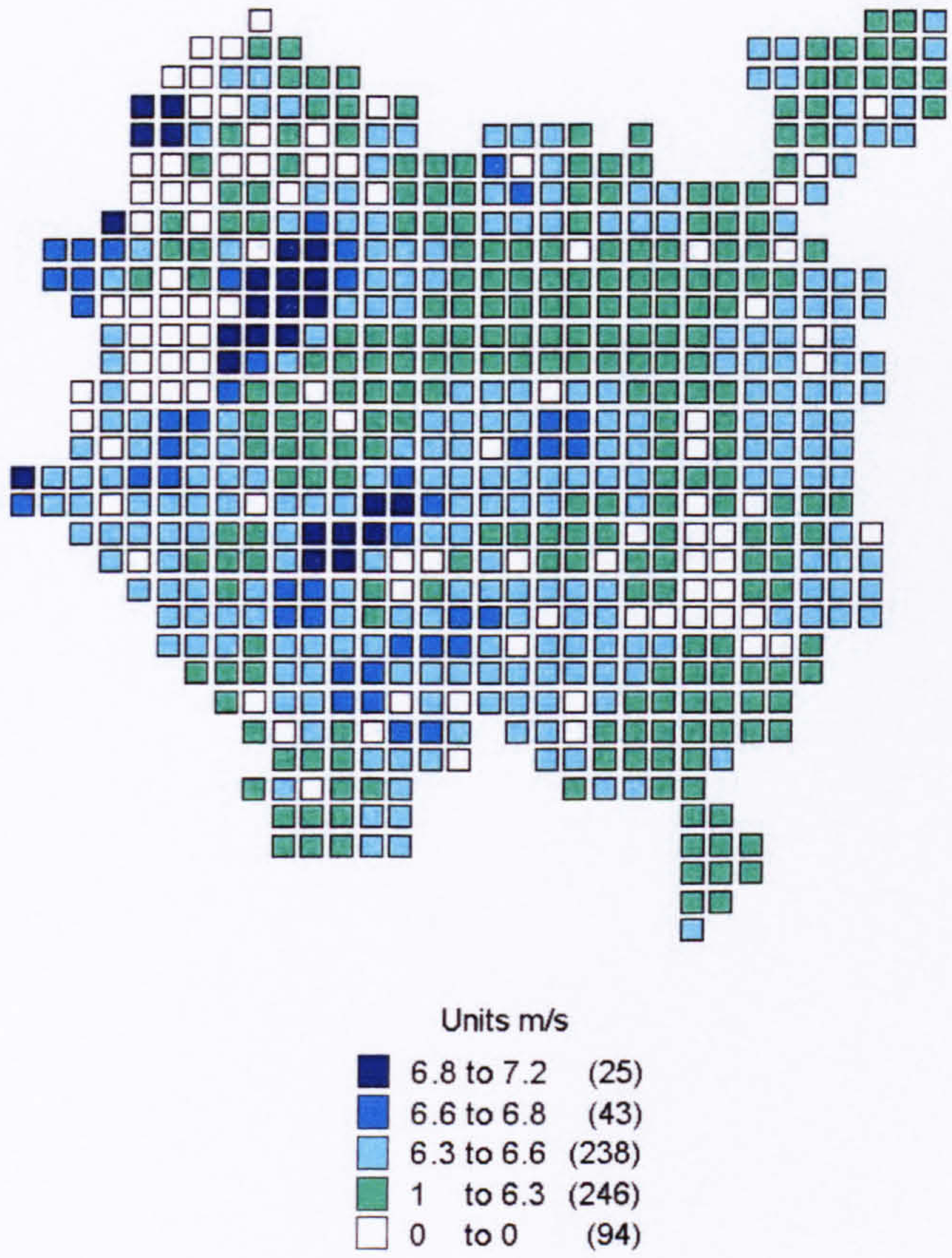

Figure 5-2. Annual average wind speeds at height 45m above ground, showing the practicable resource

Planning Policy Guidance Note 22 (Department of the Environment, 1993) supported the development of wind turbines, particularly when sited in a manner sensitive to local conditions. Following the production of the Renewables Balance Plan for Newark and Sherwood Energy Agency (Newark and Sherwood Energy Agency, 1999), and several planning applications for wind development in the district, Newark and Sherwood District Council issued Supplementary Planning Guidance on wind energy (Newark and Sherwood District Council, 1999).

5.4.2 Solar photovoltaic

Data for the total solar resource in Newark and Sherwood was taken from a map of annual average solar radiation in the report "Photovoltaics in Buildings: A design guide" (Department of Trade and Industry, 1999a). This map of UK annual average solar radiation indicated that Newark and Sherwood received between 2.4 and 2.6 kWh/m^2/day. This equated to 876 - 949 kWh/m^2/year, and given that the area of Newark and Sherwood district was 650 km^2 that meant a total solar energy falling on the district of at least 569,400,000 MWh/y.

This analysis considered the energy potential from photovoltaic (PV) on domestic buildings only.

5.4.2.1 Total resource

In the domestic sector, it was assumed that fifty percent of dwellings had a roof which was south-east to south-west facing, and which was able to support 15 m^2 of photovoltaic modules (Land Use Consultants and IT Power, 2001). For Newark and Sherwood, this resulted in an estimated total resource of 326,723 m^2 of roof area capable of being used for electricity generation by photovoltaic panels. With solar irradiance at the lower end of the range, 876 kWh/m^2/year, and an efficiency of fifteen percent, this equates to 42,931 MWh per year generating potential for the total resource.

5.4.2.2 Practicable resource

There was an estimated 43,563 households in Newark and Sherwood. An analysis of listed buildings in Newark and Sherwood indicated that 1,004 listed domestic dwellings would be unsuitable for solar energy development. This left a potential 42,559 domestic dwellings in Newark and Sherwood suitable for PV development.

Based on the Energy Efficiency Office Report 11 (Evans and Herring, 1989), and energy housing surveys in Leicester, the DREAM model (Boyle, 1994) assumed a house roof area of 90m^2. The same average was assumed for Newark and Sherwood for this analysis.

42,559 Newark and Sherwood households equated to approximately 3,830,310 m^2 of roof area.

Assuming all orientations are equally likely, one third of all possible orientation angles (0-360°) would be within 60° of south, so it was approximated that 35% of houses would be oriented within 60° of due south. The total roof area of properties oriented within 60° was then 1,340,609 m^2. It was also assumed that roof shape was standard with a central ridge and two surfaces at a 45° angle. This would mean half of the 1,340,609 m^2 roof area was actually oriented within 60° of due south. This leads to an estimated roof area of 670,304 m^2 oriented within 60° of due south.

Information on solar irradiance as a function of orientation and tilt was taken from "Photovoltaics in Buildings: A design guide" (Department of Trade and Industry, 1999a). Irradiance on a slope angled at 45° was between eighty percent and ninety five percent of the theoretical maximum provided that orientation was within 60° of due south. Assuming that the annual average solar radiation at Newark and Sherwood was at the lowest end of the scale then the theoretical maximum solar irradiance on a horizontal surface was 876 $kWh/m^2/y$. Eighty percent of the theoretical maximum was 700 $kWh/m^2/y$. This would be the minimum amount of solar radiation falling on a 45° angled surface oriented within 60° of due south in Newark and Sherwood. The estimation of PV resource was therefore based on the lowest possible value that the irradiance could take, and the estimated solar potential was, as a result, likely to be an under estimation.

The output from a PV or solar hot water system can be estimated using the formula:

$$\textbf{Irradiance } x \textbf{ area } x \textbf{ efficiency = output.} \qquad \textbf{(5-2)}$$

Photovoltaic system efficiencies were typically fifteen percent (Department of Trade and Industry, 1999a; Land Use Consultants and IT Power, 2001). Assuming 700 $kWh/m^2/y$ fell on 670, 304 m^2 of roof area, and system efficiencies were fifteen percent, this resulted in a practicable resource estimate of 70,382 MWh/y of photovoltaic electricity. This estimate assumed all suitably oriented roofs were fitted with photovoltaic panels on the entire south facing slope.

Further assumptions needed to be made as to the suitability of these dwellings for the installation of PV systems. Some may not be suitable because of a lack of roof area (i.e. in flats), or the roof structure may be unsuitable for the fixing of the collector or array. Based on assumptions within the Dynamic Regional Energy and Emissions Assessment Model (Boyle, 1994) it was assumed that fifty percent of dwellings facing within 60° of south would be suitable for PV. This resulted in a potential 7,448 domestic dwellings with good orientation and potential for PV systems.

PV systems do not typically cover all, or even half, of a roof area. A $40m^2$ array of PV cells would be needed to meet all the annual electricity requirements of an average household (average annual household electricity demand in the UK assumed to be 4.2 MWh/y based on domestic sector electricity demand and the number of domestic households (Department of Trade and Industry, 1996)). The calculation of the practicable resource for PV therefore incorporated four potential array sizes. These are shown in Table 5-2. This estimate assumes fifteen percent efficiency, 700 $kWh/m^2/y$ solar irradiance, and fifty percent of the domestic dwellings oriented within 60° of south suitable for installation of PV.

Table 5-2. The practicable solar resource using PV

Area m^2	Efficiency	Per house output kWh/y	Number of houses with system	Output MWh/y
10	15%	1,050	7,448	7,820.4
20		2,100		15,640.8
30		3,150		23,461.2
40		4,200		31,281.6

A renewable resource assessment for solar energy would normally include some estimate of the potential for solar hot water systems. The final estimate of the practicable resource for PV should therefore assume that not all 7,448 properties suitable for solar energy exploitation would actually fit a PV panel. This analysis assumed that sixty percent of available houses were fitted with hot water systems and the other forty percent (approximately 3,000 domestic dwellings) were fitted with a 20 m^2 PV array. This size of system was chosen because typical residential systems vary from one to four kWp, which equated to 7.1 m^2 to 30.4 m^2 of BP Solar BP585 (unit maximum power output 85 Wp, size 0.647 m^2 (BP Solar, 2002)) and 20 m^2 was therefore in the middle of the typical size range for domestic systems. The practicable PV electricity potential for Newark and Sherwood, taking these limits into account, is shown in Table 5-3.

Table 5-3. The electricity generation potential of the practicable PV energy in Newark and Sherwood

	Total output MWh/ y	**Number of Newark and Sherwood households served***	**% of Newark and Sherwood households served**
2979 systems, 20 m^2	6,256	1,490	3.4%

*The number of households served is the number of households whose electricity demand can be met entirely by the technology concerned. This is based on a UK annual average domestic electricity consumption of 4.2 MWh, derived from information contained in the *"Digest of United Kingdom Energy Statistics 1996"* (Department of Trade and Industry, 1996).

5.4.2.3 Development implications

In order to generate electricity from PV to the full practicable resource, approximately 3,000 households would need to have a 20m^2 PV panel installed. That equated to 6.8 percent of Newark and Sherwood households. Compared with the density of PV development required for the UK government to meet its share of EU targets in the renewables white paper (European Commission, 1997), which was 0.3 percent of existing housing stock (Land Use Consultants and IT Power, 2001), this was a significantly large number of installations. Realistically, development of PV in Newark and Sherwood would be most dependent upon costs (which have fallen rapidly (Department of Trade and Industry,1999a)), the introduction of incentives (such as the Solar Grants scheme launched by Energy Saving Trust in 2002 (Energy Saving Trust, no date)) and the development of technology (such as to reduce production costs through new processes or to improve efficiencies through new materials).

5.4.3 Hydro-electricity

The data used in the hydro-electricity section was supplied by Chris Naish of Energy Technology Support Unit (Naish, 1998). All potential hydro sites in Nottinghamshire were identified by Energy Technology Support Unit in preparation for a resource assessment for the county of Nottinghamshire (Duffin, 1998). In each case, the data for the potential hydro site included an analysis of electricity generation potential. It was only necessary to identify the potential Nottinghamshire sites which were within Newark and Sherwood district, and to calculate the number of households the resultant electricity could supply. This is shown in Table 5-4.

5.4.3.1 Total resource

Table 5-4. Electricity generation potential for small scale hydro in Newark and Sherwood

Grid reference	Location	Mean flow (m^3/s)	Plant capacity (kW)	Annual electricity production (MWh)	Unit cost (p/ kWh) using 8% discount rate
SK770535	Averham	76.41	338	2073	2
SK801554	Newark Nether Weir	78.70	610	2939	2
SK732495	Hazleford Ferry/Weir	76.25	990	3825	2
SK615393	Holme Sluice	75.04	890	3438	2
SK809612	Cromwell Weir	78.71	1510	4630	3
SK650405	Stoke Weir	75.39	890	3119	3
SK793537	Parnhams Weir	77.03	690	2720	3
SK689437	Gunthorpe Weir	75.64	1170	3587	3
SK842480	Mill Farm	1.68	14	67	10

5.4.3.2 Practicable resource

The weir at Averham was in a relatively poor state of repair. This was located next to Staythorpe power station. Newark Nether weir was in the town centre, with poor access to the site. The river was tidal at Cromwell weir, which prohibited hydro development. At Stoke weir there was not enough room for development to take place. There was poor access to due to the town centre location of Parnhams weir. Any development at Gunthorpe weir may interfere with an ancient monument at the site. The relatively high cost of project development at Mill Farm resulted in a high unit cost. Whilst this site could be developed, in practice it was not economic to do so.

Taking the above site constraints into account, only three potential hydro sites were available in the district. The electricity generation potential of these sites is shown in Table 5-5.

The combined hydro resource at these three potential sites was enough to generate 9,300MWh of electricity a year. This was enough electricity to meet the power needs of 5.1 percent of Newark and Sherwood households.

Table 5-5. The electricity generation potential of the practicable hydro resource in Newark and Sherwood

	Potential annual electricity generated (MWh)	**Number of households served***	**% of Newark & Sherwood households served**
Averham Weir	2,073	493	1.1
Hazleford Ferry/Weir	3,825	911	2.1
Holme sluice	3,438	819	1.9
Total	9,336	2,223	5.1

*The number of households served is the number of households whose electricity demand can be met entirely by the technology concerned. This is based on a UK annual average domestic electricity consumption of 4.2 MWh, derived from information contained in the *"Digest of United Kingdom Energy Statistics 1996"* (Department of Trade and Industry, 1996).

5.4.3.3 Development implications

There were relatively few development implications associated with these three hydro-electric schemes. Care should be taken in hydro development to ensure minimum flow rates are maintained and impact on local wildlife is ameliorated.

5.4.4 Biomass

Ministry of Agriculture Fisheries and Food provided data (Dobson, 1999) for Newark and Sherwood district, which listed the number and size of holdings which farmed animals and various crops. This data was from the agricultural census statistics 1997. Ministry of Agriculture Fisheries and Food data for the whole of Nottinghamshire was also obtained, from the same survey (Ministry of Agriculture Fisheries and Food, 1997), which detailed the number and size of holdings, and number of animals in the County.

Animal waste

5.4.4.1 Total resource

In order to calculate the possible energy available from anaerobic digestion of farm animal wastes it was first necessary to estimate the number of animals in Newark and Sherwood. Ministry of Agriculture Fisheries and Food figures for Newark and Sherwood (Dobson, 1999) detailed the number of holdings, but not the number of animals. This had to be estimated from Ministry of Agriculture Fisheries and Food figures for Nottinghamshire as a whole (Ministry of Agriculture Fisheries and Food, 1997). For Nottinghamshire the number of holding and number of animals was available for 1997. Therefore the average number of animals per holding was calculated for Nottinghamshire, and applied to the number of holdings in Newark and Sherwood, to estimate the number of animals. This estimate is shown in Table 5-6.

Table 5-6. Estimated number of farm animals in Newark and Sherwood

Livestock type	Average no. of animals per holding	No. of holdings in Newark and Sherwood	Estimated no. of livestock in Newark and Sherwood
Cattle and calves	86.49	200	17,299
Pigs	935.39	61	57,059
Sheep	286.85	94	26,964

Dung production rates for different animal types were obtained from a report by Baldwin for ADAS (Baldwin, 1993). This data is shown in Table 5-7. This data was needed in order to estimate the total amount of animal waste arising in Newark and Sherwood. Since sheep dung was not normally centrally collected, and there were no figures available for the number of hens in Newark and Sherwood, only waste arising from cattle and pigs was estimated.

Table 5-7. Dung production rates for different animals (Baldwin, 1993)

Livestock type	Litres/ day	% dry matter	Kg/day	Biogas yield m^3/kg	Biogas volume m^3/day	Biogas value MJ/m^3	Biogas energy MJ/day
Cattle	57	10	5.7	0.26	1.5	20-24	30
Pigs	4	10	0.4	0.3	0.12	24-28	3.1
1000 hens	14	25	28.5	0.38	10.83	24-28	281

The biogas production rate for anaerobic digestion of cow slurry was 0.0263 m^3/litre, and for pigs it was 0.03 m^3/litre, based on the information in Table 5-7 from Baldwin (1993). The annual biogas production rate from cow waste was therefore 547 m^3/year, and for pig waste 43.8 m^3/year. Using a standard calorific value for biogas it was then possible to calculate the total energy available. The calorific value of biogas (which is seventy percent methane (Richards, 1984)) was 6.34 kWh/m^3 (Baldwin,1993). Table 5-8 shows the total calorific value of pig and cattle waste in the district.

Table 5-8. The total resource - electricity generation from farm animal waste in Newark and Sherwood

Livestock type	Number of animals in Newark and Sherwood	Potential biogas generation by anaerobic digestion (m^3 per year)	Potential annual energy generated (MWh per year))
Cows	17,299	9,465,520	60,011.4
Pigs	57,059	2,499,184	15,844.8

5.4.4.2 Anaerobic digestion: Practicable resource

Practical use of anaerobic digesters on UK farms has shown that gas yields were typically sixty percent of the theoretical maximum. It was therefore assumed that biogas rates from anaerobic digestion were $0.01578 m^3$/litre for cow slurry and $0.018 m^3$/litre for pig slurry.

Not all animal dung can be collected, slurried and fed into the anaerobic digester. A collection rate of thirty five percent was assumed (based on reported slurry collection by Rix, Kelly and Mortimer (1998) and figures in Baldwin (1993a)). Using these assumptions, a maximum practical gas yield from anaerobic digestion was calculated for cattle and pig waste, as shown in Table 5-9, and the potential electricity generation from that gas yield was estimated. Typical generation systems used with anaerobic digesters achieve conversion efficiencies of thirty percent. On average, twenty six percent of input energy is converted to output electricity, and sixteen percent of input energy is converted to surplus, useful heat (Baldwin, 1993a).

Table 5-9. The practicable resource - electricity generation from farm animal waste in Newark and Sherwood

Livestock type	Number of animals in Newark and Sherwood	Potential biogas generation by anaerobic digestion (m^3 per year)	Potential annual electricity generated (MWh per year))
Cows	17,299	1,987,136	3,275.6
Pigs	57,059	524,829	865.1

The electricity yield and the number of domestic households which could be served by the generated electricity are shown in Table 5-10.

Table 5-10. The energy generation potential of the practicable energy from anaerobic digestion in Newark and Sherwood

Livestock type	Number of animals in Newark and Sherwood	Per animal	All animals	Number of Newark and Sherwood households served electricity *	% of Newark and Sherwood households served electricity
		Yearly production	Yearly production		
		Electricity kWh/yr.	Electricity MWh/yr.		
Cows	17,299	189	3,275.6	780	1.79%
Pigs	57,059	15	865.1	206	0.47%

*The number of households served is the number of households whose electricity demand can be met entirely by the technology concerned. This is based on a UK annual average domestic electricity consumption of 4.2 MWh, derived from information contained in the *"Digest of United Kingdom Energy Statistics 1996"* (Department of Trade and Industry, 1996).

Energy from crops

As stated earlier, the Ministry of Agriculture Fisheries and Food provided data (Dobson, 1999) for Newark and Sherwood district, which listed the number and size of holdings which farmed animals and various crops. The raw data relating to crops is shown in Table 5-11.

Table 5-11. Crop and land use data from June 1997 agricultural census

LAND USE	**hectares**	**No. of holdings**
Total land area on holding	51,660	593
Total crops and fallow (tillage)	39,019	443
Recent and temporary grassland (<5 years)	2,482	163
Permanent grassland (>5 years)	6,136	423
Rough grazing (sole rights)	276	43
Woodland	685	122
Set-aside	1,932	270
All other land	1,131	350
CROPPING	**hectares**	**No. of holdings**
Cereals: total (excluding maize)	25,642	390
Wheat	16,502	320
Winter barley	6,957	253
Spring barley	1,794	104
Other cereals (excluding maize)	390	34
Other crops:		
Potatoes (early and main crop)	1,674	83
Sugar beet (not stockfeed)	3,084	143
Hops	0	0
Horticultural crops	556	73
Field beans and peas for harvesting dry	1,310	86
Oilseed rape	5,137	189
Linseed	701	37
Other crops and bare fallow	705	101

5.4.4.3 Total resource

The Agricultural Census figures (Ministry of Agriculture, Fisheries and Food, 1997) shown in Table 5-11 indicate that there was 685 ha of woodland and 1,932 ha of set-aside in Newark and Sherwood. In order to estimate the potential for energy crops in Newark and Sherwood, two resource types were considered: wood waste available through standard forestry practice (from thinning and felling), and new planting of energy crops on set aside land (short rotation coppice).

Assuming a notional annual forestry waste production of 6 tonnes of dried wood per hectare (Rix, Kelly and Mortimer, 1998), and that 1 tonne of wood chip (twenty percent moisture) had an energy value of 15 GJ (Department of Trade and Industry, 1994), existing woodland could provide Newark and Sherwood with 4,110 dry tonnes of forestry waste a year with an energy value of 61,650 GJ per year.

A typical arable coppice yield of 8-20 dry tonnes per hectare per year could be expected in the UK. 1 tonne of wood chips (twenty percent moisture) would provide 15 GJ. Therefore the total short rotation coppice resource for Newark and Sherwood, assuming all 1932 ha of set aside land was used, was 23,184 dry tonnes of wood chip (with an assumed yield of 12 dry tonnes per hectare (Natural Resources Institute, 1996)), 347,760 GJ of energy, per annum. These figures are detailed in Table 5-12.

Table 5-12. The total resource from energy crops in Newark and Sherwood

	Hectares available	**Annual production (dry tonnes)**	**Annual energy (GJ)**
Forest residue	685	4,110	61,650
SRC on set-aside	1,932	23,184	347,760

5.4.4.4 Practical resource

Several assumptions were made in estimating the practical resource. It was assumed that forty percent of possible forestry waste (thinnings and brash from fellings (IEA CADDET Centre for Renewable Energy, 1998)) could feasibly be collected (limitations on collection would primarily be as a result of forestry management practice at individual sites, and economics, although there may be environmental justification for the non-removal of brash, such as for the protection of soil from heavy machinery and contribution to forest diversity (van den Broek, Teeuwisse, Healion, Kent, van Wijk, Faaij and Turkenburg, 2001)). It was also assumed that sixty percent of set aside was actually suitable for plantation of short rotation coppice (the limits on site suitability related to archaeological and environmental issues, as well as access, with planting required to follow Forestry Commission guidelines). For both forest residue and short rotation coppice it was assumed that final conversion to electricity was via a combined heat and power unit with conversion efficiency of twenty five percent, wood chips at twenty percent moisture content (Department of Trade and Industry, 1994). The total wood resource in terms of tonnes, and the electricity generation potential of wood biomass, is shown in Table 5-13.

Table 5-13. Practicable wood biomass resource in Newark and Sherwood

	Annual wood fuel production (tonnes)	**Annual electricity production (MWh)**	**Number of Newark and Sherwood households served electricity ***	**% of Newark and Sherwood households served electricity**
Forestry waste	1,644	1,644	391	0.90%
SRC on set-aside	13,910	13,910	3,312	7.6%
TOTAL	15,554	15,554	3,703	8.5%

*The number of households served is the number of households whose electricity demand can be met entirely by the technology concerned. This is based on a UK annual average domestic electricity consumption of 4.2 MWh, derived from information contained in the *"Digest of United Kingdom Energy Statistics 1996"* (Department of Trade and Industry, 1996).

5.4.4.5 Development implications

For animal wastes there were development implications in terms of permissions for the digestors and for the associated combined heat and power units. In addition, since combined heat and power units could be located centrally to several digestors, there were issues of the transportation of biogas. For forestry waste there were implications in terms of transport of wood chips, storage of wood chips, and planning consents for associated combined heat and power units. Also, the by-products of the combustion process (ash or char) would need to be transported for waste disposal. For short rotation coppice there were implications in terms of transport of wood chips, as with forestry waste, and also the storage of wood chips prior to use as fuel feedstock. In addition there were issues around the use of limited numbers of species in short rotation coppice, and planting in sympathy with the landscape. As with forestry waste, there would be by-products of the combustion process which would require disposal.

5.4.5 Waste

There was the potential to recover energy from waste in landfill sites. There were four landfill sites in Newark and Sherwood (Roberts, 1998). The combined capacity of these sites was significant. All four sites took municipal solid waste. Newark and Sherwood District Council was the Waste Collection Authority for the district, whilst Nottinghamshire County Council was the Waste Disposal Authority for the district.

5.4.5.1 Total resource

Calculation of landfill gas energy potential was based on the known landfill site volume, and approximate lifetime and hourly gas collection rates based on that volume.

Table 5-14. Total landfill resource at landfill sites in Newark and Sherwood

Name	Staple Opencast Mine	Bilsthorpe Landfill site
Location	Grange Lane, Cotham.	Brailswood Road, Bilsthorpe.
Grid reference	804/488.	658/606.
Licence holder	WasteNotts Ltd. (subsidiary of Global Environmental).	WasteNotts Ltd. (subsidiary of Global Environmental).
Volume	2 million cubic metres.	1.6 million cubic metres.
Status	Began operation in March 1998.	Approximately half full in 1998.
Resource	This site would yield approximately 800 million cubic metres of landfill gas over its lifetime.	This site already had landfill gas extraction equipment installed. The company had applied for, and received, Non Fossil Fuel Obligation (4) support for electricity generation from landfill gas. The site was likely to yield approximately 640 million cubic metres over its lifetime.
Name	Fiskerton Landfill	Cotham Landfill
Location	Fiskerton Road, Southwell.	Hawton Lane, Cotham.
Grid reference	726/528.	797/483.

Table 5-14. Total landfill resource at landfill sites in Newark and Sherwood

Licence holder	WasteNotts Ltd. (subsidiary of Global Environmental).	Nottinghamshire County Council
Volume	1.3-1.5 million cubic metres.	1 million cubic metres.
Status	Coming to end, currently under restoration. Ownership will transfer to Nottinghamshire County Council at end of restoration work.	Restored and closed.
Resource	This site had no extraction system for landfill gas. Once ownership transferred to Nottinghamshire County Council, the Council would be liable for the control of landfill gas at the site. This site could potentially yield 520 cubic metres of landfill gas over its lifetime.	This site was closed and restored. There were no gas extraction facilities on site. Very little information was available on this site, since it was closed before the privatisation of the waste industry. Ownership, and therefore responsibility, was with Nottinghamshire County Council. A map of the site indicated an approximate capacity of the site of 1 million cubic metres. This would yield around 400 million cubic metres of landfill gas over the site lifetime. This site was in close proximity to the new Staple Quarry site.

On closed sites, there was the potential for a total lifetime landfill gas yield of around 920 million cubic metres (500-700 cubic metres of gas per hour). Both of these sites were the responsibility of Nottinghamshire County Council, who were required by law to control any landfill gas at these sites. Future potential, from the two sites which were still active and operational, was for a further 1,440 million cubic metres of landfill gas over the lifetime of the two sites. These sites were owned and operated by Global Environmental, who were actively pursuing landfill gas electricity generation on many of their sites. Gas extraction equipment was already installed on one of these sites and financial support through Non Fossil Fuel Obligation had been obtained for the sale of generated electricity.

Landfill gas is typically sixty percent methane and forty percent carbon dioxide, with small traces of other gases. Landfill gas containing fifty percent methane had a calorific value of about $19MJ/m^3$ (Boyle, 1996). At that calorific value, if a generation set has an efficiency of thirty percent, $1m^3$ of landfill gas could generate about 1.5kW, and a site with an output of $700m^3$ per hour could generate about 1MW each hour.

Therefore Fiskerton and Cotham could provide an estimated electricity generation from landfill gas of 0.8 to 1 MW per hour, with the generation potential at Staple Mine and Bilsthorpe slightly higher (see Table 5-15).

Table 5-15. Total electricity generation potential from landfill gas in Newark and Sherwood

Landfill site	**Potential annual electricity generation (MWh)**	**Number of households served***	**% of Newark & Sherwood households served**
Cotham	5,000	1,190	2.73%
Fiskerton	6,500	1,547	3.55%
Bilsthorpe	8,500	2,024	4.65%
Staple	11,000	2,619	6.01%

*The number of households served is the number of households whose electricity demand can be met entirely by the technology concerned. This is based on a UK annual average domestic electricity consumption of 4.2 MWh, derived from information contained in the *"Digest of United Kingdom Energy Statistics 1996"* (Department of Trade and Industry, 1996).

5.4.5.2 Practicable resource

Given that Fiskerton and Cotham were both closed and no suitable landfill gas collection system had been installed there was little opportunity to generate electricity from landfill gas at these sites. The two modern sites, which had been engineered to higher modern standards and were still in use, had a landfill gas resource of almost 20,000 MWh annual electricity generation, enough for more than 4,500 households (or 10.66 percent of the domestic electricity demand of the district).

5.5 The total renewable electricity resource for Newark and Sherwood District

Table 5-16 summarises the results of the renewable resource assessment of Newark and Sherwood district.

Table 5-16. The total renewable resource estimate for Newark and Sherwood district

<table>
<tr><th colspan="3">Renewable energy type</th><th>Annual electricity generation (MWh)</th><th>Number of existing households served*</th><th>Percentage of existing of Newark & Sherwood households served</th></tr>
<tr><td rowspan="7">Wind</td><td rowspan="3">wind speed 6.8 ms^{-1} and above</td><td>63 large turbines</td><td>71,766</td><td>17,087</td><td>39.22</td></tr>
<tr><td>7 large turbines</td><td>7,974</td><td>1,899</td><td>4.36</td></tr>
<tr><td>7 small turbines</td><td>3,294</td><td>784</td><td>1.8</td></tr>
<tr><td rowspan="2">wind speed 6.6 ms^{-1} and above</td><td>23 large turbines</td><td>24,279</td><td>5,780</td><td>13.27</td></tr>
<tr><td>23 small turbines</td><td>10,038</td><td>2,390</td><td>5.49</td></tr>
<tr><td rowspan="2">wind speed 6.3 ms^{-1} and above</td><td>25 large turbines</td><td>21,650</td><td>5,155</td><td>11.83</td></tr>
<tr><td>25 small turbines</td><td>8,950</td><td>2,131</td><td>4.89</td></tr>
<tr><td colspan="3">Photovoltaic</td><td>6,256</td><td>1,490</td><td>3.4</td></tr>
<tr><td colspan="3">Hydro</td><td>9,336</td><td>2,223</td><td>5.1</td></tr>
<tr><td colspan="3">Animal waste</td><td>4,141</td><td>986</td><td>2.26</td></tr>
<tr><td colspan="3">Energy from crops</td><td>15,554</td><td>3,703</td><td>8.5</td></tr>
<tr><td colspan="3">Landfill gas</td><td>19,500</td><td>4,643</td><td>10.66</td></tr>
<tr><td rowspan="2">TOTAL</td><td colspan="2">Maximum wind generation</td><td>126,553</td><td>30,132</td><td>69.14</td></tr>
<tr><td colspan="2">Minimum wind generation</td><td>58,081</td><td>13,829</td><td>31.27</td></tr>
</table>

5.6 Comparison of resource estimate with demand modelling

Demand modelling in Chapter 4 showed that a high growth tariff scenario would result in 12.09 percent of domestic electricity demand from renewables, and a low growth scenario would result in 8.87 percent of electricity demand from renewables, by 2025.

In order to determine whether Newark and Sherwood district could meet renewable electricity demand under these two scenarios, it was first necessary to estimate domestic electricity demand in the district.

Firstly the average household electricity demand was estimated. DREAM predicted a total annual electricity demand prediction of 3,364,439 x 10^9 J, or 934,566 MWh, in 2025. The total number of households was predicted to be 184,712 in 2025. Electricity demand in 2025, for the business as usual scenario, was therefore 5.06 MWh per year per household.

Then the number of households in Newark and Sherwood was predicted to 2025. In 1995, there were 43,563 households and 104,500 people in the district. Using the same trends in population and households as in the DREAM business as usual scenario led to an estimate of 59,886 households in Newark and Sherwood in 2025.

Therefore, district domestic electricity demand was predicted to be 302,998 MWh per year in 2025 (based on 59,886 households with average annual electricity consumption 5.06 MWh).

Assuming low growth in green tariffs, uptake of 8.87 percent equated to 26,876 MWh per year of green electricity demand in Newark and Sherwood in 2025.

Assuming high growth in green tariffs, uptake of 12.09 percent equated to 36,632 MWh per year of green electricity demand in Newark and Sherwood in 2025.

These figures are summarised in Table 5-17.

Table 5-17. Possible green electricity demand in Newark and Sherwood district by 2025

Number of Newark and Sherwood households	Electricity demand per household	Low growth green electricity demand	High growth green electricity demand
43,563 (1995)	4.2 MWh/year (1996)	26,876 MWh/year (2025)	36,632 MWh/year (2025)
59,886 (2025)	5.06 MWh/year (2025)		

Given that the total renewable resource for Newark and Sherwood was in the region of 58,081 to 126,553 MWh per year, this analysis showed that the district could be self-sufficient in meeting the green electricity demand of its domestic residents under both the low growth and high growth green tariff scenarios.

5.7 Summary

A case study renewable resource assessment was completed for Newark and Sherwood district. The wind resource estimate, completed using the Department of Trade and Industry NOABL database, varied from 3,294 MWh per year to 71,766 MWh per year, dependent upon the size and number of turbines in the district. The photovoltaic resource, estimated from UK solar radiation maps and available roof area, was around 6,256 MWh per year. The hydro-electric resource in the district was approximately 9,336 MWh per year, based on information from Energy Technology Support Unit data on small-scale hydro power in Nottinghamshire. Electricity generation potential from anaerobic digestion of animal waste was estimated as 4,141 MWh per year, and from energy crops approximately 15,554 MWh per year. Landfill gas could contribute around 20,000 MWh a year of electricity generation. This gave a total of 76,437 MWh per year of estimated renewable electricity resource for Newark and Sherwood District, which equated to 275,173 billion Joules. This is shown in Table 5-18.

Table 5-18. A summary of the renewable resource potential in Newark and Sherwood available from different technologies

	Total annual electricity output (MWh_e)	**Number of Newark and Sherwood households served electricity**	**% of Newark and Sherwood households whose electricity needs are met**
WIND (25 x 600 kW turbines)	21,650	5,155	11.83%
PV (2,979 systems)	6,256	1,490	3.4%
HYDRO (3 schemes)	9,336	2,223	5.1%
Anaerobic digestion (pig and cow waste)	4,141	986	2.26%
Energy from crops	15,554	3,703	8.5%
Landfill gas (2 sites)	19,500	4,643	10.66%
TOTAL	76,437	18,200	41.75%

DREAM modelling predicted a green electricity demand for Leicester of 298,395 billion Joules by 2025 for the low growth scenario and 406,856 billion Joules for the high growth scenario. Extrapolating DREAM modelling to predict population and household numbers in Newark and Sherwood, it was estimated that green tariff electricity demand in the district could be 26,876 MWh per year under the low growth scenario and 36,632 MWh per year under the high growth scenario. The renewable resource assessment therefore indicated that Newark and Sherwood could be self-sufficient in meeting green electricity demand from green tariff uptake.

Chapter 6: Conclusions and recommendations for further work

6.1 Summary of preceding chapters

In chapter one the aims and objectives of the research were presented. The investigation wished to address the hypothesis "consumer choice in the UK domestic electricity market will not lead to an increased demand for, and generation by, renewable energy". The three objectives of the research were: to measure public willingness to pay for renewable electricity, to estimate the level of generation required to meet future green power demand within future electricity demand scenarios, and to determine the local potential for renewable energy to meet local green power demand through a case study. Three stages of the investigation were briefly described. The first stage was an investigation of public willingness to pay for renewable electricity. The second stage estimated the level of generation required to meet future green power demand through the use of an energy model. The third stage determined local potential for renewable energy to match local green power demand through a case study.

Chapter two presented the context of the investigation: the UK electricity supply industry, UK energy policy, renewable energy and green tariffs. Competition in electricity supply in the domestic sector of the UK market was phased in over 1998 and 1999. Retail competition provided opportunities and threats to public policy initiatives such as demand side management, low income/fuel poverty programmes and renewable energy. This chapter described the historical subsidy support for renewable energy in the UK through the Non Fossil Fuel Obligation, the expiry of that support mechanism in 1998, and stated UK government policy for ten percent of electricity from renewable sources by 2010.

In addressing the first objective of the research, a questionnaire was designed and administered to measure public willingness to pay for renewable electricity. The results of this work were presented in chapter three. The questionnaire was administered to a section of the population of Leicester who had contacted the Energy Efficiency Advice Centre. Results showed that the proportion of the population willing to pay more for renewable electricity was 35.85 +/- 3.59 percent ($N=636$, $\alpha=0.05$). The mean premium which the population were willing to pay was 19.11 +/- 2.48 percent ($N=219$, $\alpha=0.05$).

Factor analysis of the attitudinal variables resulted in three identified factors, environmental concern combined with individual responsibility and action, environmental concern combined with government responsibility and zero cost, and electricity purchasing not price based. Multiple regression was carried out and results indicated that willingness to pay could be predicted using three independent variables (explaining thirty two percent of variability): environmental concern combined with individual responsibility and action, electricity purchasing not price based, and whether the respondent had visited the Ark. A relationship between premium and cumulative willingness to pay was determined for the survey results. The data obtained had the line of best fit

$$Y = 100e^{(-0.04)M - 1.25}$$

where Y was the cumulative percentage of the population willing to pay percentage premium M.

Comparisons between the survey of those who had contacted the Energy Efficiency Advice Centre, the Leicester random sample survey and the national survey indicated a significant difference in proportions willing to pay more locally compared to nationally ($Z=6.037$, $p=0.01$), and no significant difference with the random local sample and the local sample who had contacted the Energy Efficiency Advice Centre (Z=0.184, p=0.573).

Chapter four presented work which addressed the second objective of the research. A review of energy models was completed, and a model chosen. A sensitivity analysis of the model was completed, which indicated that model outputs were most significantly affected by changes in internal temperature, heat loss parameter, number of residents, people per household and floor area. The model was then used to predict green electricity demand to 2025, based on willingness to pay results, from wind, hydro, photovoltaic and biomass technology and from a mix of all four technologies. Model scenarios were created based on a two percent premium, eight percent premium, and fifteen percent premium. Uptake was predicted based on the relationship between tariff and cumulative percentage willing to pay. Results indicated that, if green tariff uptake in Leicester equalled the willingness to pay levels of the postal survey, then by 2025 the green electricity demand at the three tariff levels could be met entirely by wind, entirely by hydro, partly by photovoltaic, partly by biomass, or entirely by a mix of all four technologies. Two further scenarios were developed, based on assumptions of product diffusion, and incorporating a mix of the four renewable electricity technologies considered. A low growth in green tariff uptake resulted in 8.87 percent of 2025 electricity demand being met by renewable sources. High growth in green tariff uptake resulted in 12.09 percent of 2025 electricity demand being met by renewable sources.

In Chapter five the third objective of the research was addressed. A renewable resource assessment was completed for a case study area, Newark and Sherwood district in Nottinghamshire. Practicable resource estimates were made for electricity generating renewable technologies: wind, photovoltaic, hydro-electric, biomass and waste. The total practicable resource for the district was 76,437 MWh per year. Given the energy model predictions for growth in electricity demand per household to 5.06 MWh per year, and using the same model assumptions to estimate the growth in the number of Newark and Sherwood households (59,886 in 2025), district electricity demand was predicted at 302,998 MWh per year in 2025. Under the low growth scenario and high growth scenario for green tariff uptake, green electricity demand was estimated to be lower than the practicable resource estimate. This therefore indicated that Newark and Sherwood district could be self-sufficient under the two product diffusion green tariff scenarios developed.

6.2 Conclusions

Results of the questionnaire showed around thirty six percent of the population sampled were willing to pay more for renewable electricity. Given that the domestic sector consumed almost thirty four percent of all electricity supplied in 2001 (Department of Trade and Industry, 2002), this stated willingness could equate to a significant proportion of the UK electricity supply. Multiple regression indicated that attitude and environmental experience influenced willingness to pay. The research may have benefited from more detailed analysis of attitudinal factors and the methods by which they can be operationalised. In this research the contingent valuation question was an open ended bid elicitation, of the format used in MORI's national research and Colbourne's Leicester research, in order to enable direct comparison with other results. However, a dichotomous choice format may have been a better approach to take, and the proposed program in the question could have been more detailed.

Results of the DREAM modelling showed that, under the model assumptions, biomass and photovoltaic could not, by themselves, meet demand. This was due primarily to assumptions regarding market share of biomass-fired combined heat and power, and efficiency and suitable available roof space for domestic installation of photovoltaics. No means was available within the modelling software to run iterative scenarios to ensure local renewable resources met predicted green tariff uptake, so this was done by hand. If this had formed the vast majority of the research task then an alternative method may have been sought.

Two further model scenarios investigated a low growth and high growth tariff uptake situation, which were proposed as more appropriate scenarios given actual green tariff uptake levels in the UK and US, and experience of product diffusion by other green products. Results indicated that 8.87 percent of domestic electricity demand would be supplied by a green tariff under a slow growth scenario, and 12.09 percent in a high growth scenario, by 2025. Given that the domestic sector consumed thirty four percent of all electricity supplied in 2001, to contribute an equal share to a ten percent target the domestic sector would need to generate demand for 3.4 percent of all electricity from renewables. A low growth scenario would result in three percent of all electricity coming from renewables as a result of green tariff demand, and a high growth scenario would result in four percent of all electricity coming from renewables as a result of green tariff demand. Therefore, under the product diffusion models the domestic sector was close to meeting, or exceeding, its fair share of the ten percent target by 2025 (but not by 2010, which is the actual target deadline). This was a very interesting result which ideally would have benefitted from further investigation, using product diffusion data from UK environmental products and early data on product diffusion for green tariff products in the UK and US.

The case study results indicated that it was possible for one district to meet all local renewable electricity demand under the high growth scenario with local renewable generation. The data investigated for a renewable resource assessment was for a case study area which differed to the questionnaire administration district and the DREAM scenario area. The research would have benefitted from having a case study area of Leicester City for the renewable resource assessment, had that data been available.

This research concluded, therefore, that the domestic sector could contribute towards government targets for renewable electricity through consumer choice alone (based on the assumptions in the high growth uptake scenario), and that this could be delivered through local small scale generation. However, achieving a share of the target which equated to the domestic sector's share of electricity consumption would only be achieved under a high growth scenario by 2025. By 2010, market forces within a high growth scenario would only achieve around seven percent of domestic electricity from renewables. These scenarios did not incorporate any assumptions on the effect of the Renewables Obligation or Climate Change Levy, and Government policy has shifted significantly since the formulation of the research hypothesis. These changes resulted in the removal of green supply tariff offerings from the market as suppliers gain greater financial benefit from the use of Renewables Obligation Certificates to meet the Renewables Obligation than to redeem certificates to verify green supply. Government policy of a ten percent target by 2010 could not be delivered through green tariff offerings in the domestic sector alone.

6.3 Recommendations for further work

Further investigation of beliefs, attitudes, intention and action regarding the behaviour of purchasing green tariff electricity would provide greater knowledge of the link between stated willingness to pay more for renewables and actual observed behaviour. It would also enable researchers to better understand the link between beliefs, attitudes and intention, and could form the basis of an educational programme to encourage greater uptake of green tariff offerings.

Further modelling work would be beneficial in relation to possible future green tariff uptake scenarios. This could expand upon the work presented here, and by Wiser, Bolinger, Holt and Swezey (2001), to develop product diffusion models for the UK market which have been validated based on other "green" product life cycles in UK markets.

This entire investigation dealt only with the domestic sector. Given the pressure on local and central government, industry and the commercial sector to be environmentally responsible and deliver best-value, future market trends and fiscal incentives (such as the Climate Change Levy) may encourage these sectors to consider the purchase of green tariffs. Further research could therefore usefully be carried out into willingness to pay, beliefs, attitudes, intentions and behaviours in these sectors, environmental purchasing behaviour in organisations in relation to electricity, and modelling of future green tariff demand in these sectors, to determine their possible contribution to renewable electricity policy goals.

6.4 Contribution to knowledge

This research contributed to an existing body of research into willingness to pay for renewable electricity, and supported the hypothesis that willingness was related to attitude and to environmentally-related experience. It supported the hypothesis that local levels of willingness to pay were significantly higher than from national average willingness to pay surveys. It supported the hypothesis that, under product diffusion models, the domestic sector could contribute close to (low growth scenario) or more than (high growth scenario) its fair share (based on the domestic sector's share of total electricity consumption) of a ten percent target for electricity from renewable sources by 2025. The research also supported the hypothesis that delivery of renewable electricity to meet green tariff demand can be achieved locally. This approach was unusual, given the existing body of research, since it brought several distinct strands together to investigate how willingness to pay could actually result in the delivery of increased renewable electricity generation at the local scale.

6.5 Summary

This research showed that significant proportions (thirty six percent) of the population (Leicester residents who had contacted the Energy Efficiency Advice Centre) were willing to pay more for renewable electricity. Product diffusion modelling demonstrated that consumer demand for green tariffs in the domestic sector could deliver a fair share towards government targets by 2025. A renewable resource assessment case study showed that the demand for renewable electricity could be met locally. Therefore, based on the assumptions detailed in this thesis, consumer choice in the UK electricity market would lead to an increased demand for, and generation by, renewable electricity.

Thsi was based on several assumptions, not least of which was the assumption that green supply tariffs in the market place would offer one hundred percent additionality. Policy changes since the start of this research period have made this unlikely, but despite changes to policy and supply offerings, the research demonstrated that significant demand for green supply tariffs could exist in the domestic electricity market.

Appendix I: Appendix to chapter 3: the willingness to pay survey

I.1 Questionnaire

Energy Efficiency Advice Centre
Customer follow-up Questionnaire

Please complete as much of this questionnaire as possible. All the information given will be treated in the strictest confidence and will be taken into consideration in further schemes.

Once the questionnaire is returned you will be entered in our monthly prize draw.

SECTION A

We would like to know what improvements you have carried out as a result of the advice you were given. This information will be used to help improve the future work of the Energy Efficiency Advice Centre

1. Do you remember being given advice by the Energy Efficiency Advice Centre? ☐ Yes ☐ No

If you answered NO to question 1 please move to question number 19.

2. Did you think the information you received from the Energy Efficiency Advice Centre was:

		Very	Quite	Not Very	Don't Know
a.	Informative	☐	☐	☐	☐
b.	Interesting	☐	☐	☐	☐
c.	Motivating	☐	☐	☐	☐
d.	Accurate	☐	☐	☐	☐
e.	Relevant	☐	☐	☐	☐
f.	Coherent	☐	☐	☐	☐
g.	Professional	☐	☐	☐	☐

(please tick ONE box for each of the above categories)

3. Did you carry out any of the following improvements to your home as a result of the advice given to you by the Energy Efficiency Advice Centre?

Improvement	Yes	No
Cavity Wall Insulation	☐	☐
Internal Solid Wall Insulation	☐	☐
External Solid wall Insulation	☐	☐
Loft Insulation	☐	☐
Floor Insulation	☐	☐
Secondary Glazing	☐	☐
Double Glazing	☐	☐
Triple Glazing	☐	☐
Low Emissivity Glazing	☐	☐
Draughtproofing	☐	☐
Windows and doors	☐	☐
Skirting boards	☐	☐
Condensing Boiler	☐	☐
Are you aware of the difference between a condensing boiler and a combination boiler?	☐	☐
Radiator shelves	☐	☐
Foil behind radiators	☐	☐

Improvement	Yes	No
Heating Controls	☐	☐
Programmer/Timer	☐	☐
Room Thermostat	☐	☐
Thermostatic Radiator Valves	☐	☐
Boiler Manager	☐	☐
Do you know what a boiler manager is?	☐	☐
Automatic Charge Control	☐	☐
Do you know what this is?	☐	☐
Hot Water Cylinder Thermostat	☐	☐
Hot Water Cylinder Insulation *(3 inches)*	☐	☐
Hot Water Timer	☐	☐
Hot Water Pipe Insulation	☐	☐
Heat Recovery Fans	☐	☐
(Do you know what these are?)	☐	☐
Low Energy Lamps	☐	☐
How Many?		

4. Has the house felt warmer since the works were carried out? ☐ Yes ☐ No

5. If you answered YES to Question 4 please select from the following list the two measures that you feel were most important in terms of making the house feel warmer.

Improvement

A Cavity Wall Insulation
B Internal Solid Wall Insulation
C External Solid wall Insulation
D Loft Insulation
E Floor Insulation
F Secondary Glazing
G Double Glazing
H Triple Glazing
I Low Emissivity Glazing
J Draught proofing (Windows and doors)
K Draught proofing (skirting boards)
L Condensing Boiler
M Radiator shelves
N Foil behind radiators
O Programmer/Timer
P Room Thermostat
Q Radiator valves
R Boiler manager
S Automatic charge Control
T Hot Water Cylinder thermostat
U Hot Water Cylinder insulation
V Hot water timer
W Hot Water Pipe insulation
X Heat recovery fans
Y Low Energy Lamps
Z Energy Efficient appliance

Most Important ____ Least Important ____

(please print one letter on each line)

6. Do you think you have saved money on your fuel bills since the works were carried out? ☐ Yes ☐ No

7. If you answered YES to Question 6 please select from the following list the two measures that you feel were most important in terms of reducing your fuel bills

Improvement

A Cavity Wall Insulation
B Internal Solid Wall Insulation
C External Solid wall Insulation
D Loft Insulation
E Floor Insulation
F Secondary Glazing
G Double Glazing
H Triple Glazing
I Low Emissivity Glazing
J Draught proofing (Windows and doors)
K Draught proofing (skirting boards)
L Condensing Boiler
M Radiator shelves
N Foil behind radiators
O Programmer/Timer
P Room Thermostat
Q Radiator valves
R Boiler manager
S Automatic charge Control
T Hot Water Cylinder thermostat
U Hot Water Cylinder insulation
V Hot water timer
W Hot Water Pipe insulation
X Heat recovery fans
Y Low Energy Lamps
Z Energy Efficient appliance

Most Important ____ Least Important ____

(Please print one letter on each line)

8. Do you heat more of the rooms in your house since the energy efficiency works were carried out? ☐ Yes ☐ No

9. Did you purchase any energy efficient appliance(s)? ☐ Yes ☐ No

If you answered YES to Question 9 please indicate the type of appliance and energy rating.

Appliance	Rating A	B	C	D	E	F	G	Don't Know
Fridge	☐	☐	☐	☐	☐	☐	☐	☐
Freezer	☐	☐	☐	☐	☐	☐	☐	☐
Fridge/Freezer	☐	☐	☐	☐	☐	☐	☐	☐
Washing Machine	☐	☐	☐	☐	☐	☐	☐	☐
Tumble drier	☐	☐	☐	☐	☐	☐	☐	☐
Dishwasher	☐	☐	☐	☐	☐	☐	☐	☐

(Please indicate type of appliance purchased and energy rating)

10. Have you stopped using any of the energy efficiency improvements or products? ☐ Yes ☐ No

11. If you answered YES to question 10, please explain:

____

____

____

____

12. Have visitors to your home shown an interest in the energy efficiency works? ☐ Yes ☐ No

13. How did you raise the money for the improvements?

☐ Grant aid ☐ From savings
☐ Extension of mortgage ☐ Loan from Bank or Building Society
☐ From family or relatives ☐ Directly from wages/salary
☐ Other ____________
(*please state*)

14. Which of the statements below best sums up your opinion of the energy efficiency advice you were given?

☐ I am very satisfied with the energy efficiency advice
☐ I am satisfied with the energy efficiency advice
☐ I am neither satisfied nor dissatisfied with the energy efficiency advice
☐ I am dissatisfied with the energy efficiency advice
☐ I am very dissatisfied with the energy efficiency advice

15. Were you given enough information about energy efficiency work? ☐ Yes ☐ No

16. If you answered No to question 15, what information would you have welcomed?

____

17. Can you suggest any improvements to the advice given by the Leicester Energy Efficiency Advice Centre?

____

18. Would you have carried out more work if you had been offered quotations by recommended, reputable contractors? ☐ Yes ☐ No

19. Have you visited the Energy Efficiency Centre on Market Place South, Leicester?
(This does not refer to the British Gas 'Energy Centre' on Market Street.) ☐ Yes ☐ No

20. Have you visited the Eco-House at Western Park, Leicester? ☐ Yes ☐ No

21. Have you visited The Ark in Leicester's St Martins Square? ☐ Yes ☐ No

22. Would you like to receive a summary of advice on energy efficiency from Energy Sense? ☐ Yes ☐ No

23. Would you like a home visit from Energy Sense staff? ☐ Yes ☐ No

24. Are you intending to carry out further energy efficiency improvements? ☐ Yes ☐ No

25. If you answered YES to Question 24, please outline what improvements you intend to carry out and whether they are DIY or contracted:

____

Please also indicate how much money you are thinking of spending.

☐ Up to £100 ☐ £101 - £500 ☐ £501-£2,000 ☐ over £2,000

26. If you are thinking of having more work carried out would you like either of the following services;

☐ Quotations from reputable contractors from the Energy Efficiency Centre.
☐ An agency service whereby all the work is organised and overseen by a City Council Officer.

SECTION B Environmentally Friendly Electricity

Electricity is currently made by burning coal, oil or gas or from nuclear fuel. Only 2% of our electricity is currently being made from more environmentally friendly sources. This includes things like wind, solar power, or waste. These sources can be called 'green' or 'renewable' energy sources.

27. Would you like to be willing to pay more for renewable electricity? ☐ Yes ☐ No

IF YES, then:
Imagine that your yearly electricity bill is £100. How much EXTRA would you be willing to pay to get ALL of your electricity from renewable sources? (If you are not willing to pay any more then enter 0)

ENTER THE EXTRA AMOUNT

£ ____________

28. A company offers you a green electricity scheme. You can join the scheme at different levels. You can get a quarter of your electricity, half your electricity, three quarters of your electricity, or all your electricity, from renewables. Imagine that your yearly bill is £100. There is an extra charge of £5 to join a green electricity scheme.
For that extra £5, how much of your electricity produced from renewables is reasonable?

☐ A quarter ☐ A half
☐ Three quarters ☐ All
☐ Would not pay more

29. Please indicate the extent to which you agree or disagree with the following statements:
(PLEASE TICK ONE BOX PER STATEMENT)

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am not concerned about climate change	☐	☐	☐	☐	☐
I would be willing to change electricity company if I was offered 'green' electricity	☐	☐	☐	☐	☐
I think the way we make electricity causes air pollution	☐	☐	☐	☐	☐
I think individuals should be responsible for investment in 'green' electricity	☐	☐	☐	☐	☐
'Green' power should be supplied at no extra cost	☐	☐	☐	☐	☐
The government should not be responsible for action to increase the amount of 'green' electricity	☐	☐	☐	☐	☐
I have no preference as to how my electricity is made	☐	☐	☐	☐	☐
I would not change electricity company just for cheaper electricity	☐	☐	☐	☐	☐

30. Would you like to receive further details about 'Green' electricity? ☐ Yes ☐ No

31. Would you like to receive further details about gas or electricity companies? ☐ Yes ☐ No

SECTION C ABOUT YOU

We need to collect information about the composition of your household so that we can be sure we are accessible to all households in the City.

32. I would describe my ethnic origin as: *(please tick the appropriate box)*

- ❑ Black African
- ❑ Black Caribbean
- ❑ Black Other
- ❑ Chinese
- ❑ Indian
- ❑ Pakistani
- ❑ Other Asian
- ❑ White
- ❑ I choose not to answer
- ❑ Other (please specify) ______

33. How many people live in the house?
(please state number)

Pensioners	80+	___	Pensioners	75-79	___
Pensioners	60-74	___	Adults	18-59	___
Children	11-18	___	Children	Under 11	___

34. When did you first move into the house?

____

35. Into which of the following bands does your average household annual income fall into?
(Tick the ONE answer that BEST describes your situation)

- ❑ Less than £7,500
- ❑ £7,501 - £10,000
- ❑ £10,001 - £15,000
- ❑ £15,001 - £20,000
- ❑ £20,001 - £30,000
- ❑ £30,001 - £40,000
- ❑ More than £40,000
- ❑ I choose not to answer
- ❑ Don't know

36. Into which of the following bands does your annual gas bill fall?

- ❑ £50 - £100
- ❑ £101 - £200
- ❑ £201 - £300
- ❑ £301 - £400
- ❑ £401 - £500
- ❑ £501 - £600
- ❑ £601 - £700
- ❑ £701 - £800
- ❑ £801 - £900
- ❑ £901 - £1000
- ❑ £1001 - £1100
- ❑ £1101 - £1200

37. Into which of the following bands does your annual electricity bill fall?

- ❑ £50 - £100
- ❑ £101 - £200
- ❑ £201 - £300
- ❑ £301 - £400
- ❑ £401 - £500
- ❑ £501 - £600
- ❑ £601 - £700
- ❑ £701 - £800
- ❑ £801 - £900
- ❑ £901 - £1000
- ❑ £1001 - £1100
- ❑ £1101 - £1200

Name: ______________________
Address: ______________________

____
Postcode ____________ **Telephone** ____________

The information you provide will be entered on our computer. Where relevant, some details may be passed on to Energy Sense (A Leicester City Council initiative) or DeMonfort University's Institute of Energy & Sustainable Development.
If you do ***NOT*** wish to have your details forwarded to these organisations please tick here. ❑

By completing and returning this questionnaire your details will be entered in to our prize draw.
If you would ***NOT*** like to be included in a prize draw please tick the following box. ❑

I.2 Coding of responses

Q1. Yes = 1

No = 0

999 = not answered

Q2. Very = 3

Quite = 2

Not very = 1

Don't know = 0

999 = not answered

System = no answer required

Q3. Yes = 1

No = 0

999 = not answered

System = no answer required

Q4. Yes = 1

No = 0

999 = not answered

System = no answer required

Q5. A = Cavity wall insulation

B = Internal solid wall insulation

C = External solid wall insulation

D = Loft insulation

E = Floor insulation

F = Secondary glazing

G = Double glazing

H = Triple glazing

I = Low emissivity glazing

J = Draught proofing (windows and doors)

K = Draught proofing (skirting boards)

L = Condensing boiler

M = Radiator shelves

N = Foil behind radiators

O = Programmer / timer

P = Room thermostat

Q = Radiator valves

R = Boiler manager

S = Automatic charge control

T = Hot water cylinder thermostat

U = Hot water cylinder insulation

V = Hot water timer

W = Hot water pipe insulation

X = Heat recovery fans

Y = Low energy lamps

Z = Energy efficient appliance

999 = not answered

System = no answer required

Q6. Yes = 1

No = 0

999 = not answered

System = no answer required

Q7. A = Cavity wall insulation

B = Internal solid wall insulation

C = External solid wall insulation

D = Loft insulation

E = Floor insulation

F = Secondary glazing

G = Double glazing

H = Triple glazing

I = Low emissivity glazing

J = Draught proofing (windows and doors)

K = Draught proofing (skirting boards)

L = Condensing boiler

M = Radiator shelves

N = Foil behind radiators

O = Programmer / timer

P = Room thermostat

Q = Radiator valves

R = Boiler manager

S = Automatic charge control

T = Hot water cylinder thermostat

U = Hot water cylinder insulation

V = Hot water timer

W = Hot water pipe insulation

X = Heat recovery fans

Y = Low energy lamps

Z = Energy efficient appliance

999 = not answered

System = no answer required

Q8. Yes = 1

No = 0

999 = not answered

System = no answer required

Q9. Yes = 1

No = 0

999 = not answered

System = no answer required

Q9. A = a rating

B = b rating

C = c rating

D = d rating

E = e rating

F = f rating

G = g rating

0 = don't know

System = no answer required

Q10. Yes = 1

No = 0

999 = not answered

System = no answer required

Q12. Yes = 1

No = 0

999 = not answered

System = no answer required

Q13. 1 = grant aid

2 = extension of mortgage

3 = from family or relatives

4 = other

5 = from savings

6 = loan from bank or building society

7 = directly from wages / salary

999 = not answered

System = no answer required

Q14. 5 = very satisfied

4 = satisfied

3 = neither satisfied nor dissatisfied

2 = dissatisfied

1 = very dissatisfied

999 = not answered

System = no answer required

Q15. Yes = 1

No = 0

999 = not answered

System = no answer required

Q18. Yes = 1

No = 0

999 = not answered

System = no answer required

Q19. Yes = 1

No = 0

999 = not answered

Q20. Yes = 1

No = 0

999 = not answered

Q21. Yes = 1

No = 0

999 = not answered

Q22. Yes = 1

No = 0

999 = not answered

Q23. Yes = 1

No = 0

999 = not answered

Q24. Yes = 1

No = 0

999 = not answered

Q25. 1 = up to £100

2 = £101-£500

3 = £501-£2,000

4 = over £2,000

Q26. 1 = yes would like service

System = not answered

Q27. 1 = yes

0 = no

999 = not answered

Q28. 0 = would no pay more

1 = a quarter

2 = a half

3 = three quarters

4 = all

999 = not answered

Q29A. 1 = strongly agree

2 = agree

3 = neutral

4 = disagree

5 = strongly disagree

999 = not answered

Q29B. 1 = strongly disagree

2 = disagree

3 = neutral

4 = agree

5 = strongly agree

999 = not answered

Q29C. 1 = strongly disagree

2 = disagree

3 = neutral

4 = agree

5 = strongly agree

999 = not answered

Q29D. 1 = strongly disagree

2 = disagree

3 = neutral

4 = agree

5 = strongly agree

999 = not answered

Q29E. 1 = strongly disagree

2 = disagree

3 = neutral

4 = agree

5 = strongly agree

999 = not answered

Q29F. 1 = strongly agree

2 = agree

3 = neutral

4 = disagree

5 = strongly disagree

999 = not answered

Q29G. 1 = strongly agree

2 = agree

3 = neutral

4 = disagree

5 = strongly disagree

999 = not answered

Q29H. 1 = strongly disagree

2 = disagree

3 = neutral

4 = agree

5 = strongly agree

999 = not answered

Q30. 1 = yes

0 = no

999 = not answered

Q31. 1 = yes

0 = no

999 = not answered

Q32. Ba = Black african

Bc = Black caribbean

Bo = Black other

C = Chinese

I = Indian

P = Pakistani

Oa = Other asian

W = White

Na = I choose not to answer

O = Other

999 = not answered

Q35. 0 = I choose not to answer

1 = Don't know

2 = Less than £7,500

3 = £7,501 - £10,000

4 = £10,001 - £15,000

5 = £15,001 - £20,000

6 = £20,001 - £30,000

7 = £30,001 - £40,000

8 = More than £40,000

999 = not answered

Q36. 0 = £50 - £100

1 = £101 - £200

2 = £201 - £300

3 = £301 - £400

4 = £401 - £500

5 = £501 - £600

6 = £601 - £700

7 = £701 - £800

8 = £801 - £900

9 = £901 - £1000

10 = £1001 - £1100

11 = £1101 - £1200

999 = not answered

Q37. 0 = £50 - £100

1 = £101 - £200

2 = £201 - £300

3 = £301 - £400

4 = £401 - £500

5 = £501 - £600

6 = £601 - £700

7 = £701 - £800

8 = £801 - £900

9 = £901 - £1000

10 = £1001 - £1100

11 = £1101 - £1200

999 = not answered

I.3 Raw results

Table I-1 Frequency of social classification based on response to postcode

Social class	Frequency	Percentage of responses
1	35	4.9
2	72	10.1
3	100	14.0
4	98	13.8
5	26	3.7
6	119	16.7
7	18	2.5
8	32	4.5
9	44	6.2
10	168	23.6
TOTAL	712	100
Missing	34	
TOTAL	746	

Table I-2 "Into which of the following bands does your average household annual income fall into?"

Response	Frequency	Percentage of responses
choose not to answer	72	10.8
don't know	21	3.2
less than £7,500	201	30.2
£7,501-£10,000	87	13.1
£10,001-£15,000	89	13.4
£15,001-£20,000	56	8.4
£20,001-£30,000	88	13.2
£30,001-£40,000	32	4.8
more than £40,000	20	3.0
TOTAL	666	100
Missing	80	
TOTAL	746	

Table I-3 Frequency of respondents by gender group (derived from information on christian name and title)

Gender group	Frequency	Percentage of responses
Male	231	45.8
Female	273	54.2
TOTAL	504	100.0
Missing	242	
TOTAL	746	

Table I-4 Frequency of respondents by age group (derived from question on the number of people in the household)

Age group	Frequency	Percentage of responses
Under 60	343	58.0
Over 60	248	42.0
TOTAL	591	100.0
Missing	155	
TOTAL	746	

Table I-5 "I am not concerned about climate change."

Response	Frequency	Percentage of responses
No more	196	40.1
Quarter	110	22.5
Half	97	19.8
Three quarters	12	2.5
All	74	15.1
TOTAL	489	100
Missing	257	
TOTAL	746	

Table I-6 "I would be willing to change electricity company if I was offered 'green' electricity."

Response	Frequency	Percentage of responses
Strongly disagree	45	7.4
Disagree	69	11.3
Neutral	220	36.0
Agree	192	31.4
Strongly agree	85	13.9
TOTAL	611	100
Missing	140	
TOTAL	746	

Table I-7 "I think the way we make electricity causes air pollution."

Response	**Frequency**	**Percentage of responses**
Strongly disagree	21	3.6
Disagree	26	4.4
Neutral	179	30.6
Agree	241	41.2
Strongly agree	118	20.2
TOTAL	585	100
Missing	161	
TOTAL	746	

Table I-8 "I think individuals should be responsible for investment in 'green' electricity."

Response	**Frequency**	**Percentage of responses**
Strongly disagree	67	11.1
Disagree	112	18.5
Neutral	211	34.9
Agree	173	28.6
Strongly agree	42	6.9
TOTAL	605	100
Missing	141	
TOTAL	746	

Table I-9 "'Green' power should be supplied at no extra cost."

Response	Frequency	Percentage of responses
Strongly disagree	18	3.0
Disagree	31	5.1
Neutral	100	16.4
Agree	234	38.5
Strongly agree	225	37.0
TOTAL	608	100
Missing	138	
TOTAL	746	

Table I-10 "The government should not be responsible for action to increase the amount of 'green' electricity."

Response	Frequency	Percentage of responses
Strongly agree	33	5.4
Agree	51	8.4
Neutral	83	13.6
Disagree	177	29.1
Strongly disagree	265	43.5
TOTAL	609	100
Missing	137	
TOTAL	746	

Table I-11 "I have no preference as to how my electricity is made."

Response	Frequency	Percentage of responses
Strongly agree	19	3.3
Agree	47	8.3
Neutral	184	32.3
Disagree	205	36.0
Strongly disagree	114	20.0
TOTAL	569	100
Missing	177	
TOTAL	746	

Table I-12 "I would not change electricity company just for cheaper electricity."

Response	Frequency	Percentage of responses
Strongly disagree	107	17.1
Disagree	140	22.4
Neutral	165	26.4
Agree	165	26.4
Strongly agree	48	7.7
TOTAL	625	100
Missing	121	
TOTAL	746	

Table I-13 "Have you visited the Energy Efficiency Centre on Market Place South, Leicester?"

Response	Frequency	Percentage of responses
No	491	69.8
Yes	212	30.2
TOTAL	703	100.0
Missing	43	
TOTAL	746	

Table I-14 "Have you visited the Eco-House at Western Park, Leicester?"

Response	Frequency	Percentage of responses
No	364	51.6
Yes	341	48.4
TOTAL	705	100.0
Missing	41	
TOTAL	746	

I.4 Formulae used

I.4.1 Estimating population characteristics from the sample

I.4.1.1 Estimating mean

$$z = \frac{\bar{x} - \mu}{\sigma/(\sqrt{n})} \tag{I-1}$$

This formula was used to estimate the population mean μ using the sample mean $\bar{x}$ and the variance ($\sigma/(\sqrt{n})$ where σ is the standard deviation and n is the sample size). z is given the approximate value from look up tables for the confidence limit required. In estimating the mean premium which the population was willing to pay, a confidence limit of 0.95 was used, corresponding to z = 1.960 (Startup and Whittaker, 1982). This meant that it was ninety five percent probable that the population mean fell within the range of 19.11 ± 2.48 percent.

I.4.1.2 Estimating proportion

$$\text{error} = z \times \sqrt{\frac{p(1-p)}{n}} \tag{I-2}$$

This formula was used to estimate the proportion of people in the population willing to pay more. p is the proportion of people willing to pay more in the population. This approximately equals r/n, where n is the sample size and r is the number of people willing to pay more in the sample. The value of z is taken from look up tables and for this investigation the value of 1.960 was used (ninety five percent confidence interval). In this investigation a finite population correction was also used, since the sample size was over five percent of the population size. Using finite population correction, and replacing for p, the equation for estimating the error in p is then:

$$\text{error} = z \times \sqrt{\frac{(r/n)(1-r/n)(N-n)}{n(N-1)}} \tag{I-3}$$

In this formula, N is the population size (8,700 in this instance). The proportion willing to pay more in the population was then 35.85 ± 3.59 percent with a ninety five percent confidence interval and finite population correction.

I.4.2 Discrimination - the Pearson product-moment

$$r_s = 1 - \frac{6\sum D^2}{(N^3 - N)} \tag{I-4}$$

Where:

r = correlation coefficient;

N = number of paired scores;

D = difference between ranked scores.

I.4.3 Reliability - Spearman-Brown split half reliability

$$r_{11} = \frac{2r_{1/2}}{1 + r_{1/2}} \tag{I-5}$$

Where:

r_{11} = estimated reliability for whole questionnaire;

$r_{1/2}$ = correlation between two halves of questionnaire (calculated using Pearson product-moment formula).

I.4.4 Comparing two sets of sample results

I.4.4.1 Difference of means

$$z = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(s_1{}^2/n_1) + (s_2{}^2/n_2)}} \tag{I-6}$$

This formula applies to large samples (over fifty), where the population variances σ_1^2 and σ_2^2 are unknown and instead the unbiased estimates of variance s_1^2 and s_2^2 are used. If the value calculated for z falls outside the chosen look up value for the confidence interval then the two population means are proven to be significantly different.

I.4.4.2 Difference of proportions

$$z = \frac{(r_1/n_1 - r_2/n_2)}{pq(1/n_1 + 1/n_2)} \tag{I-7}$$

In this instance

$$p = \frac{r_1 + r_2}{n_1 + n_2}$$

and $q = 1\text{-}p$. This formula applies to large samples. It is assumed that $p_1 = p_2 = p$, that the proportions within the two populations are the same. If the value calculated for z falls outside the chosen look up value for the confidence interval then the two population proportions are proven to be significantly different.

Appendix II: Appendix to chapter 4: modelling green power demand

II.1 Methodology of the DREAM domestic model sensitivity analysis

II.1.1 Preliminary investigation of input and output parameters

The DREAM model consisted of sixty four input parameters, which were used to calculate fuel demand for cooking, space heating and water heating. A total of forty one output parameters were produced by the model.

Of the sixty four input parameters, three could not be varied within any sensible range (month length, student occupancy factor, and the electricity share of lighting and appliances) and two comprised long term local weather data (solar radiation and mean monthly rainfall).These five input parameters were therefore not varied as part of the sensitivity analysis. All input and output parameters are shown in Table II-1.

Table II-1 A complete list of input and output variables

Input variables	Output variables
Number of Residents	Annual Rolling Electricity (Billions)
Number of Students	Annual Rolling Gas (Billions)
Student Occupancy Factor	Annual Rolling Oil (Billions)
Month Length	Annual Rolling Solid (Billions)
Number of People Per Household	Annual Rolling CHPDH (Billions)
Lighting and Appliance Electricity Per Household	Monthly Grid Electricity (Billions)
Electricity Market Share for Lighting and Appliances	Model Monthly Gas (Billions)
Mains Temperature	Model Monthly Oil (Billions)
Heat Loss Parameter	Model Monthly CHPDH (Billions)
Litres Per Day of Hot Water	Model Monthly Solid (Billions)
Hot Water Temperature	Monthly PV Supplied (Billions)
Floor Area	Monthly Wind Energy Supplied (Billions)
Cooking Gains	Monthly Hydro Supplied (Billions)
Internal Temperature	Monthly Total Biomass (Billions)
Lighting and Appliance Gains	Total Households
Solar Gains	Total Population
Water and Metabolic Gains	Total Fossil Fuel Supplied (Gas)
Space Electric Share	Total Fossil Fuel Supplied (Oil)
Space Electric Efficiency	Total Fossil Fuel Supplied (Solid Fuel)
Space Gas Share	Annual Total Biomass
Space Gas Efficiency	Total Emissions (Gas, Carbon Dioxide)
Space Solid Share	Total Emissions (Gas, Sulphur Dioxide)
Space Solid Efficiency	Total Emissions (Gas, Nitrous Oxides)
Space Heat CHPDH Share	Total Emissions (Gas, VOC)
Space Heat CHPDH Efficiency	Total Emissions (Gas, Methane)
Space Heat Oil Share	Total Emissions (Gas, Carbon Monoxide)
Space Heat Oil Efficiency	Total Emissions (Gas, Black Smoke)
Water Heat CHPDH Share	Total Emissions (Oil, Carbon Dioxide)
Water Heat CHPDH Efficiency	Total Emissions (Oil, Sulphur Dioxide)
Water Heat Solid Share	Total Emissions (Oil, Nitrous Oxides)

Water Heat Solid Efficiency	Total Emissions (Oil, VOC)
Water Heat Oil Share	Total Emissions (Oil, Methane)
Water Heat Oil Efficiency	Total Emissions (Oil, Carbon Monoxide)
Water Heat Gas Share	Total Emissions (Oil, Black Smoke)
Water Heat Gas Efficiency	Total Emissions (Solid Fuel, Carbon Dioxide)
Water Heat Electric Share	Total Emissions (Solid Fuel, Sulphur Dioxide)
Water Heat Electric Efficiency	Total Emissions (Solid Fuel, Nitrous Oxides)
Cooking Electric Share	Total Emissions (Solid Fuel, VOC)
Cooking Electric Efficiency	Total Emissions (Solid Fuel, Methane)
Cooking Oil Share	Total Emissions (Solid Fuel, Carbon Monoxide)
Cooking Oil Efficiency	Total Emissions (Solid Fuel, Black Smoke)
Cooking Solid Share	
Cooking Solid Efficiency	
Cooking Gas Share	
Cooking Gas Efficiency	
Wind Speed Data	
Annual Mean Wind Speed	
Turbine CoP	
Number of Turbines	
Turbine Diameter	
Array Efficiency	
Area of Roofs South Facing	
% of Roofs Suitable For PV	
% of Suitable Roofs South Facing With PV	
Solar Radiation	
Module Efficiency	
Inverter Efficiency	
Mean Rainfall	
Peak Rainfall	
Hydro Installed	

Biomass Supply to Boiler	
Biomass Supply to CHP	
Size of CHP	
Grid Transmission Losses	

Of the remaining fifty nine input parameters, forty two were not related to renewable electricity. For these forty two parameters, a run of the DREAM model in the "business as usual" scenario was a suitable test run to use as the base case within the sensitivity analysis. The business as usual scenario was not suitable as a base case for the remaining seventeen renewable input parameters, since this scenario assumed no generation of electricity by renewable sources. An alternative base case was created for the renewable parameters.

Sensitivity analysis was carried out separately on the two sets of input variables - non renewable and renewable.

II.1.2 Results of the sensitivity analysis of non-renewable input variables

For the forty two non renewable input variables, each variable was altered by a positive increment of ten percent and negative increment of ten percent (all other variables remaining at their base case level). The percentage change in thirty four (non-renewable) output parameters were then compared, in order to determine which input parameters the model was most sensitive to. With forty two input variables, each varied by plus ten percent and minus ten percent, a total of eighty five model runs were necessary (including the business as usual comparison case).

The base case, plus ten percent, and minus ten percent values for all forty two non renewable input variables are shown in Table II-2. These variables were investigated and the effect on output variables was evaluated. These sensitivity results (for a ten percent variation in non renewable input variables) are shown in Table II-4. The input variables have been number coded to allow graphical representation of the data. Number codes are defined in Table II-3.

Results indicated that changes to five input variables resulted in the greatest change in output variables, and these five were chosen to be investigated further. Figure II-1 to Figure II-2 show the variation in a selection of five output variables as the forty two input variables are varied by plus ten percent (case a on figures) and minus ten percent (case b on figures).

Table II-2 Variations in input variables

Variable: Residents ***(month number)***	**Base case value**	**+10% value**	**-10% value**
0	358000	358000	358000
48	352000	352000	352000
96	346000	380600	311400
144	362000	398200	325800
192	370000	407000	333000
240	380000	418000	342000
288	390000	429000	351000
336	395000	434500	355500
384	402000	442200	361800
432	407000	447700	366300
480	412500	453750	371250
528	415000	456500	373500
Variable: Students			
0	13000	13000	13000
48	13768	13768	13768
96	14536	15990	13082
144	15304	16834	13774
192	16072	17692	14469
240	16840	18524	15156
288	17608	19369	15847
336	18376	20214	16538
384	19144	21058	17230
432	19912	21903	17920
480	20680	22748	18612
528	21448	23593	19303

Variable: Light and appliance electricity per household 0 48 96 144 192 240 288 336 384 432	 202 231 260 284 303 325 345 365 385 404	 202 231 286 312.4 333.3 257.5 379.5 401.5 423.5 444.4	 202 231 234 255.6 272.7 292.5 310.5 328.5 346.5 363.6
Mains temperature *(month)* 1 2 3 4 5 6 7 8 9 10 11 12	 7 6 7 9 10 11 13 15 13 11 10 9	 7.7 6.6 7.7 9.9 11 12.1 14.3 16.5 14.3 12.1 11 9.9	 6.3 5.4 6.3 8.1 9 9.9 11.7 13.5 11.7 9.9 9 8.1
Litres used per household per day	=((0.17*people_per_household+0.27)*1000/7)* (1+time/864)	=(((0.17*people_per_household+0.27)*1000/7)* (1+time/864)*1.1)	=(((0.17*people_per_household+0.27)*1000/7)* (1+time/864)*0.9)
Floor area	=if time<120 then 90 else (90-(time-120)*0.0192)	=if time<120 then 90 else ((90-(time-120)*0.0192)*1.1)	=if time<120 then 90 else ((90-(time-120)*0.0192)*0.9)
Heat loss parameter 0 48 96 144 192 240 288 336 384 432 480 528	 3.85 3.65 3.48 3.45 3.25 3.15 3.05 2.975 2.9 2.85 2.825 2.8	 3.85 3.65 3.828 3.795 3.575 3.465 3.355 3.273 3.19 3.135 3.108 3.08	 3.85 3.65 3.132 3.105 2.925 2.835 2.745 2.678 2.61 2.565 2.543 2.52

People per household 0 48 96 144 192 240 288 336 384 432 480 528	 2.67 2.64 2.61 2.58 2.55 2.52 2.49 2.46 2.43 2.4 2.37 2.34	 2.67 2.64 2.871 2.838 2.805 2.772 2.739 2.706 2.673 2.64 2.607 2.574	 2.67 2.64 2.349 2.322 2.295 2.268 2.241 2.214 2.187 2.16 2.133 2.106
Space heating oil share	=0.035-time*0.0000115	=(0.035-time*0.0000115)*1.1	=(0.035-time*0.0000115)*0.9
Space heating oil efficiency	=0.74+time*0.00009	=(0.74+time*0.00009)*1.1	=(0.74+time*0.00009)*0.9
Water heating oil share	=0.02	=0.02*1.1	=0.02*0.9
Water heating oil efficiency	=0.39+time*0.00014	=(0.39+time*0.00014)*1.1	=(0.39+time*0.00014)*0.9
Water heating gas share	=0.65-time*0.000116	=(0.65-time*0.000116)*1.1	=(0.65-time*0.000116)*0.9
Water heating gas efficiency	=0.5+time*0.00023	=(0.5+time*0.00023)*1.1	=(0.5+time*0.00023)*0.9
Water heating electric share	=0.2+time*0.000116	=(0.2+time*0.000116)*1.1	=(0.2+time*0.000116)*0.9
Water heating electric efficiency	=0.85+time*0.00016	=(0.85+time*0.00016)*1.1	=(0.85+time*0.00016)*0.9
Cooking electric share	=0.25+time*0.0001	=(0.25+time*0.0001)*1.1	=(0.25+time*0.0001)*0.9
Cooking electric efficiency	=0.25+time*0.00023	=(0.25+time*0.00023)*1.1	=(0.25+time*0.00023)*0.9
Cooking oil share	=0.025	=(0.025)*1.1	=(0.025)*09.
Cooking oil efficiency	=0.11	=(0.11)*1.1	=(0.11)*0.9
Cooking solid share	=0.025	=(0.025)*1.1	=(0.025)*0.9
Cooking solid efficiency	=0.11	=(0.11)*1.1	=(0.11)*0.9
Cooking gas share	=0.7-time*0.0001	=(0.7-time*0.0001)*1.1	=(0.7-time*0.0001)*0.9
Cooking gas efficiency	=0.11+time*0.00009	=(0.11+time*0.00009)*1.1	=(0.11+time*0.00009)*0.9
Space electric share	=0.04	=0.04*1.1	=0.04*0.9

Space electric efficiency	=0.95	=0.95*1.1	=0.95*0.9
Space gas share	=0.85	=0.85*1.1	=0.85*0.9
Space gas efficiency	=0.65+time*0.0003	=(0.65+time*0.0003)*1.1	=(0.65+time*0.0003)*0.9
Space solid share	=0.04-time*0.000023	=(0.04-time*0.000023)*1.1	=(0.04-time*0.000023)*0.9
Space solid efficiency	=0.54+time*0.0001	=(0.54+time*0.0001)*1.1	=(0.54+time*0.0001)*0.9
Water heat solid share	=0.08-time*0.000069	=(0.08-time*0.000069)*1.1	=(0.08-time*0.000069)*0.9
Water heat solid efficiency	=0.36+time*0.000093	=(0.36+time*0.000093)*1.1	=(0.36+time*0.000093)*0.9
Water heat CHPDH share	=0.05+time*0.000069	=(0.05+time*0.000069)*1.1	=(0.05+time*0.000069)*0.9
Water heat CHPDH efficiency	=0.70+time*0.000116	=(0.70+time*0.000116)*1.1	=(0.70+time*0.000116)*0.9
Space heat CHPDH share	=0.025+time*0.000035	=(0.025+time*0.000035)*1.1	=(0.025+time*0.000035)*0.9
Space heat CHPDH efficiency	=0.75+time*0.000116	=(0.75+time*0.000116)*1.1	=(0.75+time*0.000116)*0.9
Hot water temperature	=70	=70*1.1	=70*0.9
Cooking gains	=total_deliv_cook_energy/(total_households*month_length)	=(total_deliv_cook_energy/(total_households*month_length)*1.1)	=(total_deliv_cook_energy/(total_households*month_length))*0.9
Internal temp	=if (month_number<5) or (month number>9) then (15.0+time*0.006) else (18.0+time*0.006)	=if (month_number<5) or (month number>9) then ((15.0+time*0.006)*1.1) else ((18.0+time*0.006)*1.1)	=if (month_number<5) or (month number>9) then ((15.0+time*0.006)*0.9) else ((18.0+time*0.006)*0.9)
Lighting and appliance gains	=256*(1+0.35*cos (month_number*PI/6))/84	=(256*(1+0.35*cos (month_number*PI/6))/84)*1.1	=(256*(1+0.35*cos (month_number*PI/6))/84)*0.9
Solar gains	=725*(1-0.69* cos (month_number*PI/6))/84	=(725*(1-0.69* cos (month_number*PI/6))/84)*1.1	=(725*(1-0.69* cos (month_number*PI/6))/84)*1.1
Water and metabolic gains	=19+(people_per_household*78)	=(19+(people_per_household*78))*1.1	=(19+(people_per_household*78))*0.9

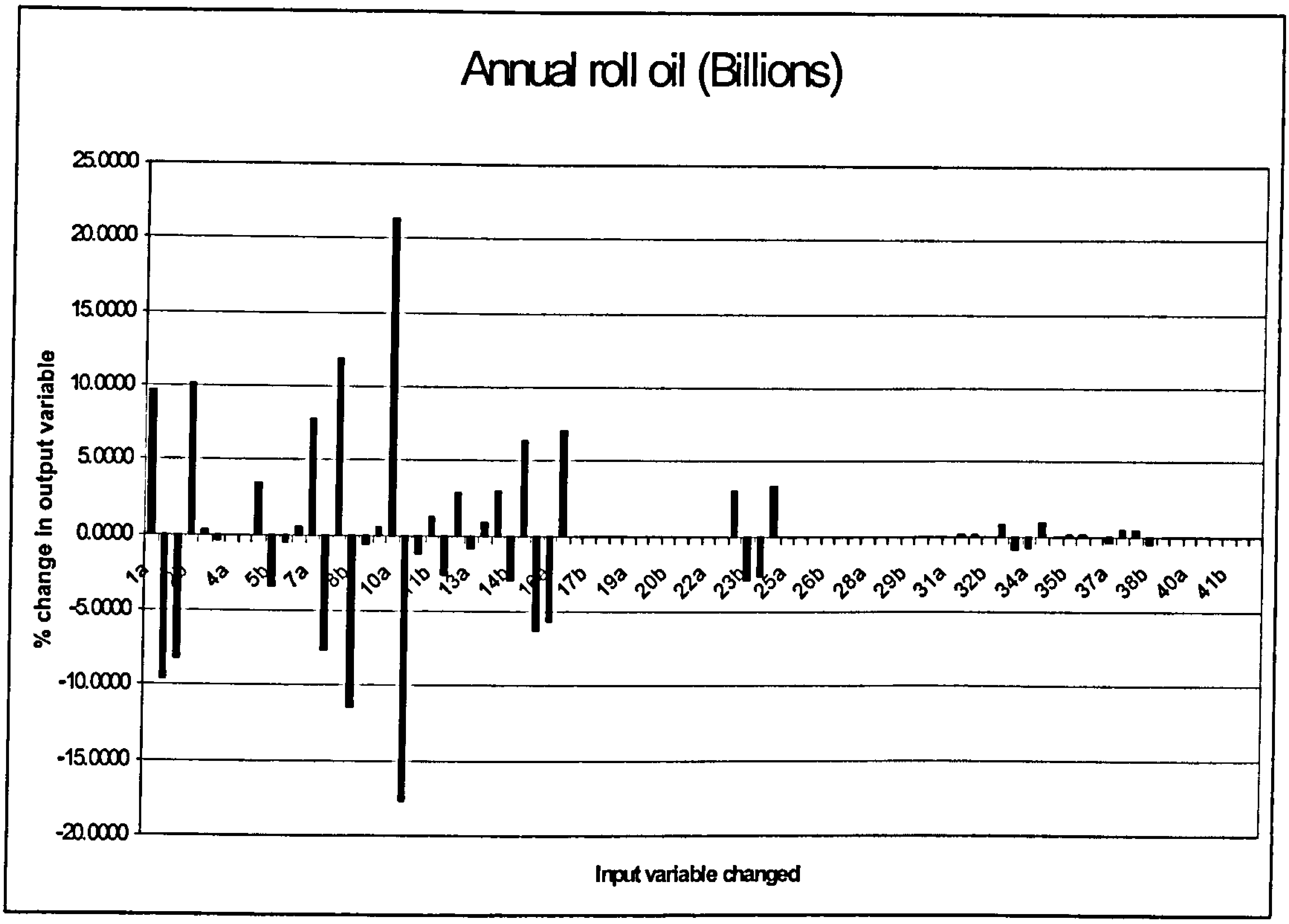

Figure II-1 Percentage change in annual rolling oil as input variables are varied

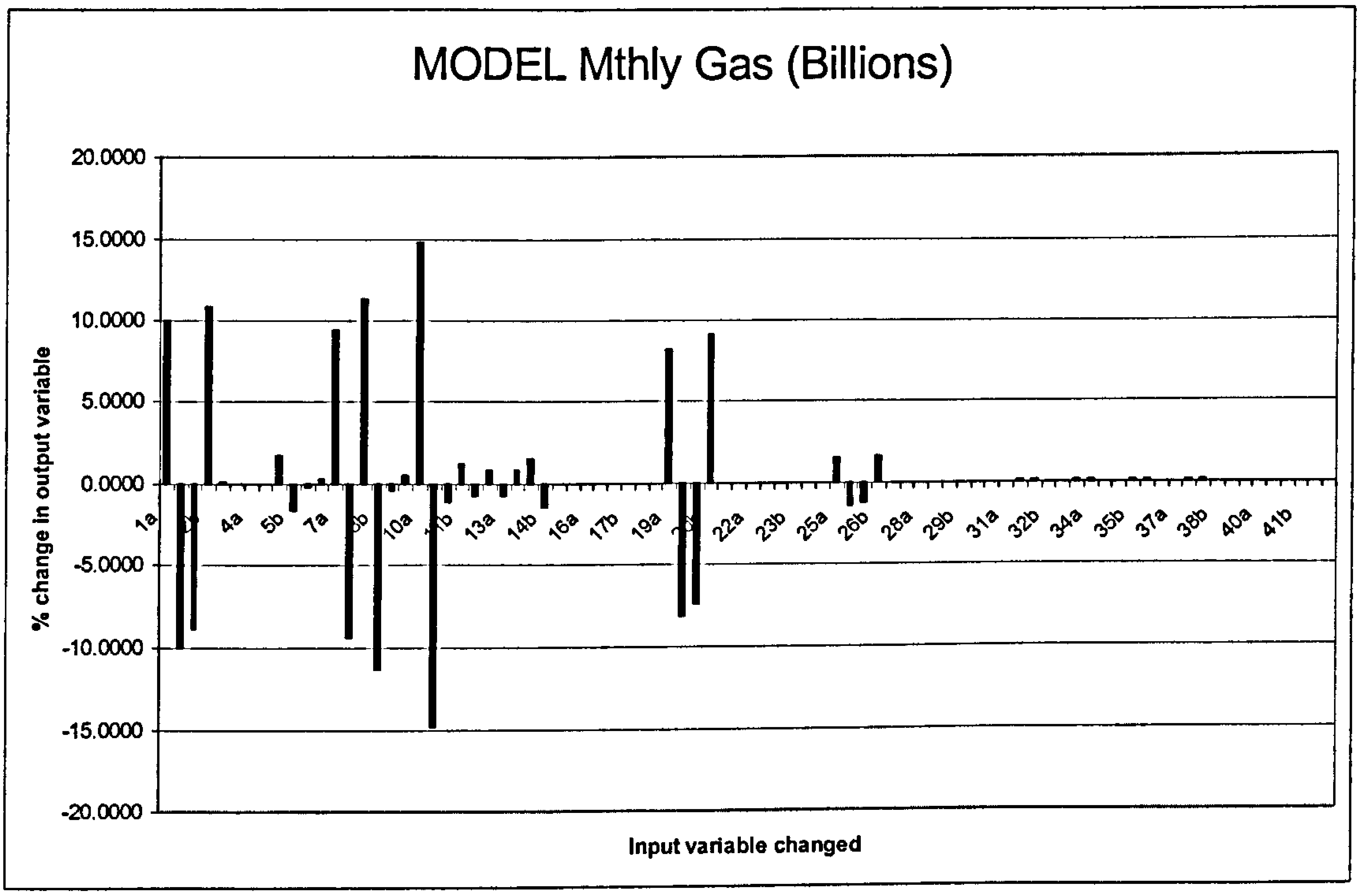

Figure II-2 Percentage change in model monthly gas as input variables are varied

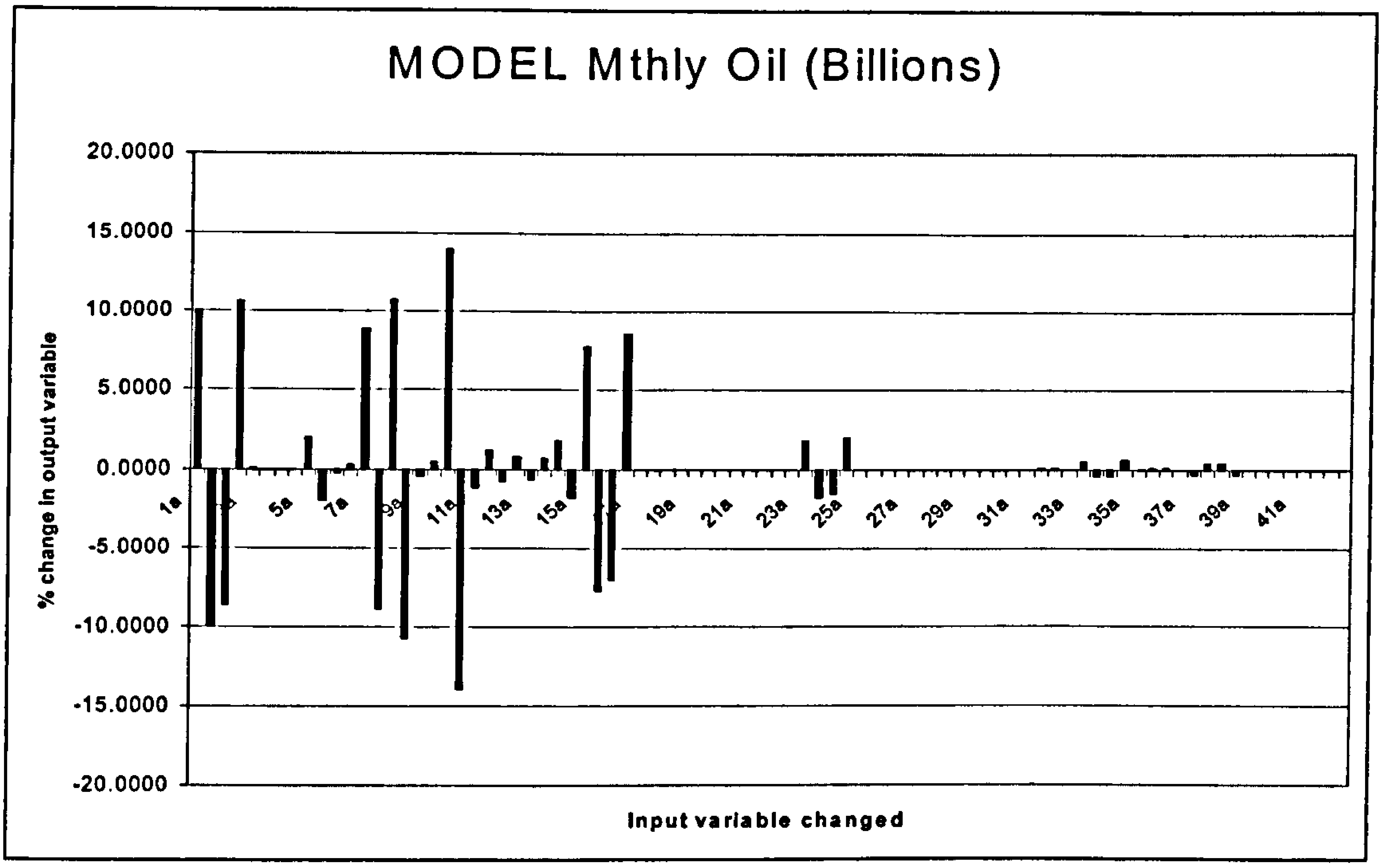

Figure II-3 Percentage change in model monthly oil as input variables are varied

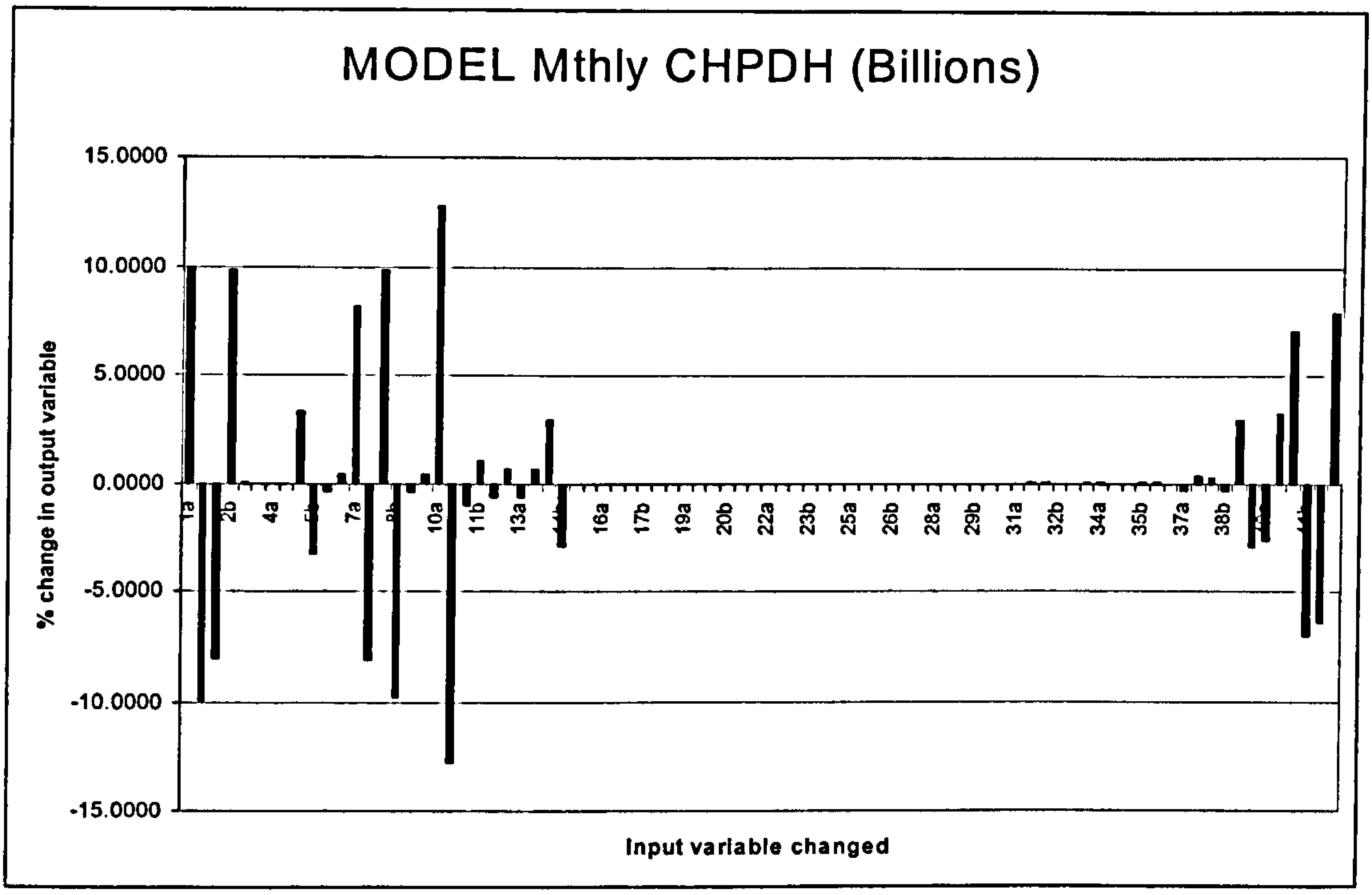

Figure II-4 Percentage change in model monthly CHPDH as input variables are varied

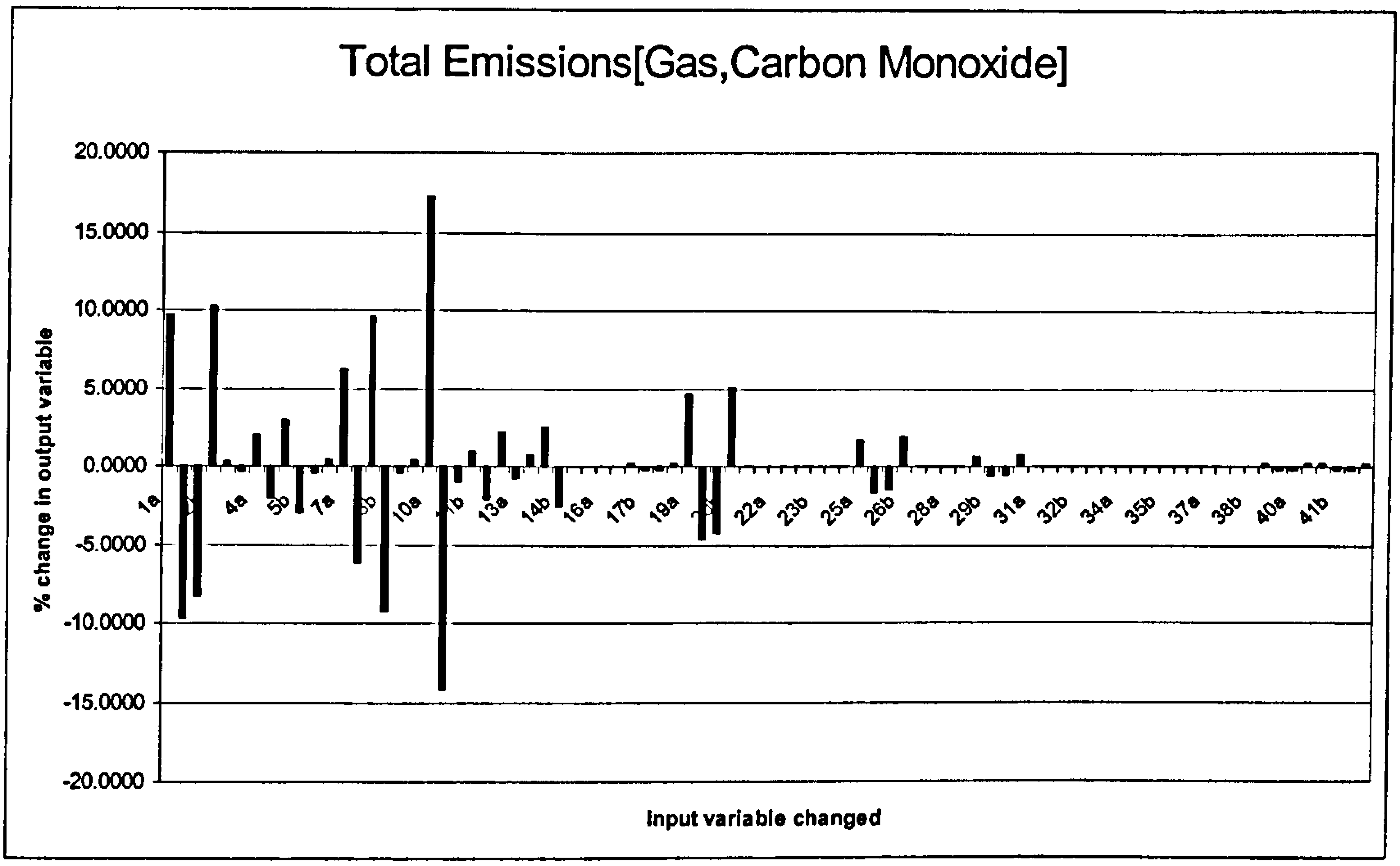

Figure II-5 Percentage change in total emissions of carbon monoxide as input variables are varied

Table II-3 Number coding of input variables

1	Residents
2	People per household
3	Students
4	Light n app elec per hh
5	Hot water temp
6	Mains temp
7	Floor area
8	Heat loss parameter
9	Cook gains
10	Internal temp
11	Light n app gains
12	Solar gains
13	Water n metabolic gains

14	Litres per day
15	Space oil share
16	Space oil efficiency
17	Space elec share
18	Space elec efficiency
19	Space gas share
20	Space gas efficiency
21	Space solid share
22	Space solid efficiency
23	Water heat oil share
24	Water heat oil efficiency
25	Water heat gas share
26	Water heat gas efficiency
27	Water heat solid share
28	Water heat solid efficiency
29	Water heat elec share
30	Water heat elec efficiency
31	Cooking elec share
32	Cooking elec efficiency
33	Cooking oil share
34	Cooking oil efficiency
35	Cooking solid share
36	Cooking solid efficiency
37	Cooking gas share
38	Cooking gas efficiency
39	Water heat CHPDH share
40	Water heat CHPDH efficiency
41	Space heat CHPDH share
42	Space heat CHPDH efficiency

Table II-4 Full results of +10%/-10% sensitivity analysis for non renewable input variables. Figures shown are the percentage changes in output from the base case, to two decimal places, with the first figure resulting from a +10% change in the input and the second figure from a -10% change in the input

	annual roll elec	annual roll gas	annual roll oil	annual roll solid	annual roll CHPDH	Mthly Grid Elec	Mthly Gas	Mthly Oil	Mthly CHPDH	Mthly Solid
Residents	9.69 -9.69	9.66 -9.66	9.66 -9.66	9.67 -9.67	9.66 -9.66	9.61 -9.61	9.98 -9.98	9.98 -9.98	9.98 -9.98	9.98 -9.99
People Per household	8.04 -9.83	8.54 -10.44	8.24 -10.07	7.13 -8.72	7.23 -8.84	8.20 -10.02	8.90 -10.88	-8.70 10.63	-8.02 9.81	-7.91 9.67
Students	0.31 -0.31	0.34 -0.34	0.34 -0.34	0.33 -0.33	0.34 -0.34	0.49 -0.49	0.02 -0.02	0.02 -0.02	0.01 -0.02	0.02 -0.02
Light n App Elec per HH	6.80 -6.80	0 0	0 0	0 0	0 0	6.16 -6.16	0 0	0 0	0 0	0 0
Hot water temp	2.45 -2.45	2.94 -2.94	3.42 -3.42	5.44 -5.44	5.37 -5.37	2.23 -2.23	1.65 -1.65	2.01 -2.01	3.34 -3.34	3.50 -3.50
Mains temp	-0.35 0.35	-0.42 0.42	-0.49 0.49	-0.78 0.78	-0.77 0.77	-0.22 0.22	-0.21 0.21	-0.26 0.26	-0.43 0.43	-0.45 0.45
Floor area	0.96 -0.96	8.53 -8.51	7.72 -7.71	5.97 -5.96	6.67 -6.66	1.85 -1.85	9.41 -9.41	8.87 -8.87	8.12 -8.12	7.56 -7.56
Heat loss par	1.47 -1.42	13.05 -12.63	11.82 -11.44	9.14 -8.85	10.21 -9.88	2.24 -2.24	11.40 -11.40	10.75 -10.75	9.84 -9.84	9.16 -9.16
Cook gains	-0.07 0.07	-0.62 0.62	-0.56 0.56	-0.43 0.43	-0.48 0.48	-0.08 0.08	-0.47 0.47	-0.45 0.45	-0.41 0.41	-0.38 0.38
Internal temp	2.65 -2.17	23.56 -19.47	21.34 -17.64	16.51 -13.65	18.44 -15.24	2.69 -2.69	14.85 -14.85	14.00 -14.00	12.81 -12.81	11.94 -11.94
Light n app gains	-0.15 0.15	-1.33 1.33	-1.21 1.21	-0.93 0.93	-1.04 1.04	-0.22 0.22	-1.21 1.21	-1.14 1.14	-1.04 1.04	-0.97 0.98
Solar gains	-0.33 0.35	-2.90 3.08	-2.62 2.79	-2.03 2.16	-2.27 2.41	-0.18 0.18	-0.78 0.78	-0.74 0.74	-0.68 0.68	-0.63 0.63
Water n metabolic gains	-0.11 0.11	-0.99 0.99	-0.90 0.90	-0.69 0.69	-0.77 0.77	-0.13 0.13	-0.72 0.72	-0.68 0.68	-0.62 0.62	-0.58 0.58
Litres per day	2.10 -2.10	2.51 -2.51	2.93 -2.93	4.66 -4.66	4.60 -4.60	2.01 -2.01	1.44 -1.44	1.75 -1.75	2.91 -2.91	3.05 -3.05

Space oil share	0 0	0 0	6.25 -6.25	0 0	0 0	0 0	0 0	7.45 -7.45	0 0	0 0
Space oil efficiency	0 0	0 0	-5.68 6.95	0 0	0 0	0 0	0 0	-7.04 8.61	0 0	0 0
Space elec share	0.78 -0.78	0 0	0 0	0 0	0 0	1.63 -1.63	0 0	0 0	0 0	0 0
Space elec efficiency	-0.70 0.86	0 0	0 0	0 0	0 0	-1.48 1.81	0 0	0 0	0 0	0 0
Space gas share	0 0	6.90 -6.90	0 0	0 0	0 0	0 0	8.22 -8.22	0 0	0 0	0 0
Space gas efficiency	0 0	-6.28 7.67	0 0	0 0	0 0	0 0	-7.47 9.13	0 0	0 0	0 0
Space solid share	0 0	0 0	0 0	4.84 -4.84	0 0	0 0	0 0	0 0	0 0	6.60 -6.61
Space solid efficiency	0 0	0 0	0 0	-4.40 5.38	0 0	0 0	0 0	0 0	0 0	-6.01 7.34
Water heat oil share	0 0	0 0	2.93 -2.93	0 0	0 0	0 0	0 0	1.75 -1.75	0 0	0 0
Water heat oil efficiency	0 0	0 0	-2.66 3.26	0 0	0 0	0 0	0 0	-1.59 1.95	0 0	0 0
Water heat gas share	0 0	2.51 -2.51	0 0	0 0	0 0	0 0	1.44 -1.44	0 0	0 0	0 0
Water heat gas effic.	0 0	-2.28 2.79	0 0	0 0	0 0	0 0	-1.31 1.60	0 0	0 0	0 0
Water heat solid share	0 0	0 0	0 0	4.66 -4.66	0 0	0 0	0 0	0 0	0 0	3.05 -3.05
Water heat solid effic.	0 0	0 0	0 0	-4.24 5.78	0 0	0 0	0 0	0 0	0 0	-2.78 3.39
Water heat elec share	2.10 -2.10	0 0	0 0	0 0	0 0	2.01 -2.01	0 0	0 0	0 0	0 0
Water heat elec effic	-1.91 2.33	0 0	0 0	0 0	0 0	-1.83 2.23	0 0	0 0	0 0	0 0

Cooking elec share	0.31 -0.31	-0.09 0.09	-0.08 0.08	-0.07 0.07	-0.07 0.07	0.29 -0.29	-0.07 0.07	-0.07 0.07	-0.06 0.06	-0.06 0.06
Cooking elec efficiency	-0.29 0.35	0.08 -0.10	0.07 -0.09	0.06 -0.07	0.07 -0.08	-0.26 0.32	0.06 -0.08	0.06 -0.07	0.06 -0.07	0.05 -0.06
Cooking oil share	0 0	0 0	0.79 -0.79	-0.02 0.02	-0.02 0.02	0 0	-0.02 0.02	0.48 -0.48	-0.02 0.02	-0.02 0.02
Cooking oil efficiency	0 0	0 0	-0.72 0.88	0.02 -0.02	0.02 -0.02	0 0	0.02 -0.02	-0.44 0.54	0.01 -0.02	0.01 -0.02
Cooking solid share	0 0	-0.03 0.03	-0.02 0.02	0.49 -0.49	-0.02 0.02	0 0	-0.02 0.02	-0.02 0.02	-0.02 0.02	0.33 -0.33
Cooking solid effic.	0 0	0.02 -0.03	0.02 -0.03	-0.44 0.54	0.02 -0.02	0	0.02 -0.02	0.02 -0.02	0.01 -0.02	-0.30 0.36
Cooking gas share	-0.05 0.05	0.11 -0.11	-0.43 0.43	-0.33 0.33	-0.37 0.37	-0.06 0.06	-0.02 0.02	-0.34 0.34	-0.31 0.31	-0.29 0.29
Cooking gas efficiency	0.05 -0.06	-0.10 0.12	0.39 -0.48	0.30 -0.37	0.34 -0.41	0.06 -0.07	0.02 -0.02	0.31 -0.38	0.28 -0.35	0.27 -0.32
Water heat CHPDH share	0 0	0 0	0 0	0 0	4.60 -4.60	0 0	0 0	0 0	2.91 -2.91	0 0
Water heat CHPDH efficiency	0 0	0 0	0 0	0 0	-4.18 5.11	0 0	0 0	0 0	-2.65 3.23	0 0
Space heat CHPDH share	0 0	0 0	0 0	0 0	5.40 -5.40	0 0	0 0	0 0	7.09 -7.09	0 0
Space heat CHPDH efficiency	0 0	0 0	0 0	0 0	-4.91	6.00 0	0 0	0 0	-6.45 7.88	0 0

Table II-4 continued.

	Total Em[Gas,Carbon Dioxide]	Total Em[Gas,Sulphur Dioxide]	Total Em[Gas,Nitrous Oxides]	Total Households	Total Population	Total FF Supplied[Gas]	Total FF Supplied[Oil]	Total FF Supplied[Solid Fuel]	Total Em [Gas,VOC]	Total Em [Gas,Methane]
Residents	9.70 -9.70	0 0	9.70 -9.70	9.52 -9.52	9.52 -9.52	9.70 -9.70	9.76 -9.76	9.78 -9.78	9.70 -9.70	9.70 -9.70
People Per household	8.37 -10.22	0 0	8.37 -10.22	-9.09 11.1 1	0 0	-8.37 10.22	-8.16 9.98	7.95 -9.72	-8.37 10.23	-8.73 10.23
Students	0.33 -0.33	0 0	0.33 -0.33	0.48 -0.48	0.48 -0.48	0.33 -0.33	0.32 -0.32	0.31 -0.31	0.33 -0.33	0.33 -0.33
Light n App Elec per HH	2.02 -2.02	0 0	2.02 -2.02	0 0	0 0	2.02 -2.02	4.79 -4.79	5.65 -5.65	2.02 -2.02	2.02 -2.02
Hot water temp	2.90 -2.90	0 0	2.90 -2.90	0 0	0 0	2.90 -2.90	2.77 -2.77	3.01 -3.01	2.90 -2.90	2.90 -2.90
Mains temp	-0.42 0.42	0 0	-0.42 0.42	0 0	0 0	-0.42 0.42	-0.40 0.40	-0.43 0.43	-0.42 0.42	-0.42 0.42
Floor area	6.23 -6.22	0 0	6.23 -6.22	0 0	0 0	6.23 -6.22	3.02 -3.02	1.86 -1.86	6.23 -6.22	6.23 -6.22
Heat loss par	9.53 -9.22	0 0	9.53 -9.22	0 0	0 0	9.53 -9.22	4.63 -4.48	2.85 -2.76	9.54 -9.22	9.54 -9.22
Cook gains	-0.45 0.45	0 0	-0.45 0.45	0 0	0 0	-0.45 0.45	-0.22 0.22	-0.14 0.14	-0.45 0.45	-0.45 0.45
Internal temp	17.22 -14.23	0 0	17.22 -14.23	0 0	0 0	17.22 -14.23	8.35 -6.90	5.15 -4.26	17.22 - 14.23	17.22 - 14.23
Light n app gains	-0.97 0.97	0 0	-0.97 0.97	0 0	0 0	-0.97 0.97	-0.47 0.47	-0.29 0.29	-0.97 0.97	-0.97 0.98
Solar gains	-2.12 2.25	0 0	-2.12 2.25	0 0	0 0	-2.12 2.25	-1.03 1.09	-0.63 0.67	-2.12 2.25	-2.12 2.25
Water n metabolic gains	-0.72 0.72	0 0	-0.72 0.72	0 0	0 0	-0.72 0.72	-0.35 0.35	-0.22 0.22	-0.72 0.72	-0.72 0.72

Litres per day	2.49 -2.49	0 0	2.49 -2.49	0 0	0 0	2.49 -2.49	2.37 -2.37	2.58 -2.58	2.49 -2.49	2.49 -2.49
Space oil share	0 0	0 0	0 0	0 0	0 0	0 0	1.90 -1.90	0 0	0 0	0 0
Space oil efficiency	0 0	0 0	0 0	0 0	0 0	0 0	-1.73 2.11	0 0	0 0	0 0
Space elec share	0.23 -0.23	0 0	0.23 -0.23	0 0	0 0	0.23 -0.23	0.55 -0.55	0.64 -0.64	0.23 -0.23	0.23 -0.23
Space elec efficiency	-0.21 0.26	0 0	-0.21 0.26	0 0	0 0	-0.21 0.26	-0.50 0.61	-0.59 0.72	-0.21 0.26	-0.21 0.26
Space gas share	4.59 -4.59	0 0	4.59 -4.59	0 0	0 0	4.59 -4.59	0 0	0 0	4.59 -4.59	4.59 -4.59
Space gas efficiency	-4.17 5.10	0 0	-4.17 5.10	0 0	0 0	-4.17 5.10	0 0	0 0	-4.17 5.10	-4.17 5.10
Space solid share	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0.87 -0.87	0 0	0 0
Space solid efficiency	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-0.79 0.96	0 0	0 0
Water heat oil share	0 0	0 0	0 0	0 0	0 0	0 0	0.89 -0.89	0 0	0 0	0 0
Water heat oil efficiency	0 0	0 0	0 0	0 0	0 0	0 0	-0.81 0.99	0 0	0 0	0 0
Water heat gas share	1.67 -1.67	0 0	1.67 -1.67	0 0	0 0	1.67 -1.67	0 0	0 0	1.67 -1.67	1.67 -1.67
Water heat gas effic.	-1.52 1.85	0 0	-1.52 1.86	0 0	0 0	-1.52 1.85	0 0	0 0	-1.52 1.86	-1.52 1.86
Water heat solid share	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0.83 -0.83	0 0	0 0
Water heat solid effic.	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-0.76 0.93	0 0	0 0
Water heat elec share	0.62 -0.62	0 0	0.62 -0.62	0 0	0 0	0.62 -0.62	1.48 -1.48	1.74 -1.74	0.62 -0.62	0.62 -0.62

Water heat elec effic	-0.57 0.69	0 0	-0.57 0.69	0 0	0 0	-0.57 0.69	-1.34 1.64	-1.59 1.94	-0.57 0.69	-0.57 0.69
Cooking elec share	0.03 -0.03	0 0	0.03 -0.03	0 0	0 0	0.03 -0.03	0.20 -0.20	0.25 -0.25	0.03 -0.03	0.03 -0.03
Cooking elec effi-ciency	-0.02 0.02	0 0	-0.02 0.02	0 0	0 0	-0.02 0.02	0.24 -0.24	-0.01 0.01	-0.02 0.03	-0.03 0.03
Cooking oil share	-0.02 0.02	0 0	-0.02 0.02	0 0	0 0	-0.02 0.02	0.24 -0.24	-0.01 0.01	-0.02 0.02	-0.02 0.02
Cooking oil effi-ciency	0.02 -0.02	0 0	0.02 -0.02	0 0	0 0	0.02 -0.02	-0.22 0.27	0.01 -0.01	0.02 -0.02	0.02 -0.02
Cooking solid share	-0.02 0.02	0 0	-0.02 0.02	0 0	0 0	-0.02 0.02	-0.01 0.01	0.01 -0.01	-0.02 0.02	-0.02 0.02
Cooking solid effic.	0.02 -0.02	0 0	0.02 -0.02	0 0	0 0	0.02 -0.02	0.01 -0.01	-0.08 0.09	0.02 -0.02	0.02 -0.02
Cooking gas share	0.04 -0.04	0 0	0.04 -0.04	0 0	0 0	0.04 -0.04	-0.17 0.17	-0.10 0.10	0.04 -0.04	0.04 -0.04
Cooking gas effi-ciency	-0.04 0.05	0 0	-0.04 0.05	0 0	0 0	-0.04 0.05	0.15 -0.19	-0.09 0.12	0.05 -0.06	-0.10 0.12
Water heat CHPDH share	0.19 -0.19	0 0	0.19 -0.19	0 0	0 0	0.19 -0.19	0 0	0 0	0.19 -0.19	0.19 -0.19
Water heat CHPDH efficiency	-0.18 0.21	0 0	-0.18 0.21	0 0	0 0	-0.18 0.21	0 0	0 0	-0.17 0.21	-0.17 0.21
Space heat CHPDH share	0.23 -0.23	0 0	0.23 -0.23	0 0	0 0	0.23 -0.23	0 0	0 0	0.23 -0.23	0.23 -0.23
Space heat CHPDH efficiency	-0.21 0.25	0 0	-0.21 0.25	0 0	0 0	-0.21 0.25	0 0	0 0	-0.21 0.25	-0.21 0.25

Table II-4 continued.

	Total Em [Gas,Carbon Monoxide]	Total Em [Gas,Black Smoke]	Total Em [Oil,Carbon Dioxide]	Total Em [Oil,Sulphur Dioxide]	Total Em [Oil,Nitrous Oxides]	Total Em [Oil,VOC]	Total Em [Oil,Methane]	Total Em [Oil,Carbon Monoxide]	Total Em [Oil,Black Smoke]	Total Em [Solid Fuel,Carbon Dioxide]
Residents	9.70 -9.70	0 0	9.76 -9.76	9.76 -9.76	9.76 -9.76	9.73 -9.76	9.73 -9.76	9.75 -9.76	9.76 -9.76	9.78 -9.78
People Per Household	-8.37 10.23	0 0	-8.16 9.98	-8.16 9.98	-8.16 9.98	-8.19 9.95	-8.18 9.95	-8.17 9.97	-8.16 9.98	-7.95 9.72
Students	0.33 -0.33	0 0	0.32 -0.32	0.32 -0.32	0.32 -0.32	0.30 -0.33	0.30 -0.33	0.31 -0.32	0.32 -0.32	0.31 -0.31
Light n App Elec per HH	2.02 -2.02	0 0	4.79 -4.79	4.79 -4.79	4.79 -4.79	4.77 -4.80	4.77 -4.80	4.78 -4.79	4.79 -4.79	5.65 -5.65
Hot water temp	2.90 -2.90	0 0	2.77 -2.77	2.77 -2.77	2.77 -2.77	2.75 -2.78	2.75 -2.78	2.76 -2.77	2.77 -2.77	3.01 -3.01
Mains temp	-0.42 0.42	0 0	-0.40 0.40	-0.40 0.40	-0.40 0.40	-0.41 0.38	-0.41 0.38	-0.40 0.40	-0.40 0.40	-0.43 0.43
Floor area	6.23 -6.22	0 0	3.02 -3.02	3.02 -3.02	3.02 -3.02	3.00 -3.03	3.00 -3.03	3.02 -3.02	3.02 -3.02	1.86 -1.86
Heat loss param	9.54 -9.22	0 0	4.63 -4.48	4.63 -4.48	4.63 -4.48	4.61 -4.50	4.61 -4.50	4.62 -4.48	4.63 -4.48	2.85 -2.76
Cook gains	-0.45 0.45	0 0	-0.22 0.22	-0.22 0.22	-0.22 0.22	-0.25 0.22	-0.25 0.22	-0.22 0.22	-0.22 0.22	-0.14 0.14
Internal temp	17.22 -14.23	0 0	8.35 -6.90	8.35 -6.90	8.35 -6.90	8.34 -6.92	8.34 -6.92	8.35 -6.91	8.35 -6.90	5.15 -4.26
Light n app gains	-0.97 0.97	0 0	-0.47 0.47	-0.47 0.47	-0.47 0.47	-0.49 0.46	-0.49 0.46	-0.47 0.47	-0.47 0.47	-0.29 0.29
Solar gains	-2.12 2.25	0 0	-1.03 1.09	-1.03 1.09	-1.03 1.09	-1.04 1.09	-1.04 1.09	-1.03 1.09	-1.03 1.09	-0.63 0.67
Water n metabolic gains	-0.72 0.72	0 0	-0.35 0.35	-0.35 0.35	-0.35 0.35	-0.35 0.33	-0.35 0.33	-0.35 0.35	-0.35 0.35	-0.22 0.22

Litres per day	2.49 -2.49	0 0	2.37 -2.37	2.37 -2.37	2.37 -2.37	2.34 -2.37	2.34 -2.37	2.37 -2.37	2.37 -2.37	2.58 -2.58
Space oil share	0 0	0 0	1.90 -1.90	1.90 -1.90	1.90 -1.90	1.88 -1.91	1.88 -1.91	1.90 -1.91	1.90 -1.91	0 0
Space oil efficiency	0 0	0 0	-1.73 2.11	-1.73 2.11	-1.73 2.11	-1.74 2.10	-1.74 2.10	-1.73 2.11	-1.73 2.11	0 0
Space elec share	0.23 -0.23	0 0	0.55 -0.55	0.55 -0.55	0.55 -0.55	0.55 -0.55	0.55 -0.55	0.54 -0.55	0.55 -0.55	0.64 -0.64
Space elec efficiency	-0.21 0.26	0 0	-0.50 0.61	-0.50 0.61	-0.50 0.61	-0.52 0.60	-0.52 0.60	-0.50 0.60	-0.50 0.60	-0.59 0.72
Space gas share	4.59 -4.59	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Space gas efficiency	-4.17 5.10	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Space solid share	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0.87 -0.87
Space solid efficiency	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-0.79 0.96
Water heat oil share	0 0	0 0	0.89 -0.89	0.89 -0.89	0.89 -0.89	0.87 -0.90	0.87 -0.90	0.89 -0.89	0.89 -0.89	0 0
Water heat oil efficiency	0 0	0 0	-0.81 0.99	-0.81 0.99	-0.81 0.99	-0.82 0.98	-0.82 0.98	-0.81 0.99	-0.81 0.99	0 0
Water heat gas share	1.67 -1.67	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Water heat gas effic.	-1.51 1.86	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Water heat solid share	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0.83 -0.83
Water heat solid effic.	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-0.76 0.93
Water heat elec share	0.62 -0.62	0 0	1.48 -1.48	1.48 -1.48	1.48 -1.48	1.48 -1.50	1.47 -1.50	1.47 -1.48	1.48 -1.48	1.74 -1.74
Water heat elec effic	-0.57 0.69	0 0	-1.34 1.64	-1.34 1.64	-1.34 1.64	-1.36 1.64	-1.36 1.64	-1.35 1.64	-1.35 1.64	-1.59 1.94
Cooking elec share	0.03 -0.03	0 0	0.20 -0.20	0.20 -0.20	0.20 -0.20	0.19 -0.22	0.19 -0.22	0.20 -0.20	0.20 -0.20	0.25 -0.25
Cooking elec efficiency	-0.03 0.03	0 0	-0.18 0.22	-0.18 0.22	-0.18 0.22	-0.19 0.19	-0.19 0.19	-0.18 0.21	-0.18 0.22	-0.23 0.28

Cooking oil share	-0.02 0.02	0 0	0.24 -0.24	0.24 -0.24	0.24 -0.24	0.22 -0.25	0.22 -0.25	0.24 -0.24	-0.01 0.01	-0.01 0.01
Cooking oil effi-ciency	0.02 -0.02	0 0	-0.22 0.27	-0.22 0.27	-0.22 0.27	-0.22 0.25	-0.22 0.25	-0.22 0.26	-0.22 0.27	0.01 -0.01
Cooking solid share	-0.02 0.02	0 0	-0.01 0.01	-0.01 0.01	-0.01 0.01	-0.03 0	-0.03 0	-0.01 0.01	-0.01 0.01	0.08 -0.08
Cooking solid effic.	0.02 -0.02	0 0	0.01 -0.01	0.01 -0.01	0.01 -0.01	0 -0.03	0 -0.03	0.01 -0.01	0.01 -0.01	-0.08 0.09
Cooking gas share	0.04 -0.04	0 0	-0.17 0.17	-0.17 0.17	-0.17 0.17	-0.19 0.16	-0.19 0.16	-0.17 0.16	-0.17 0.17	-0.10 0.10
Cooking gas effi-ciency	-0.04 0.05	0 0	0.15 -0.19	0.15 -0.19	0.15 -0.19	0.14 -0.19	0.14 -0.19	0.15 -0.19	0.15 -0.19	0.09 -0.12
Space solid share	0 0	4.84 -4.84	0 0	0 0	0 0	0 0	0 0	6.60 -6.61	0 0	0 0
Space solid effi-ciency	0 0	-4.40 5.38	0 0	0 0	0 0	0 0	0 0	-6.01 7.34	0 0	0 0
Water heat oil share	2.93 -2.93	0 0	0 0	0 0	0 0	1.75 -1.75	0 0	0 0	0 0	0 0
Water heat oil effi-ciency	-2.66 3.26	0 0	0 0	0 0	0 0	-1.59 1.95	0 0	0 0	0 0	0 0
Water heat gas share	0 0	0 0	0 0	0 0	1.44 -1.44	0 0	0 0	0 0	0 0	0 0
Water heat gas effic.	0 0	0 0	0 0	0 0	-1.31 1.60	0 0	0 0	0 0	0 0	0 0
Water heat solid share	0 0	4.66 -4.66	0 0	0 0	0 0	0 0	0 0	3.05 -3.05	0 0	0 0
Water heat solid effic.	0 0	-4.24 5.78	0 0	0 0	0 0	0 0	0 0	-2.78 3.39	0 0	0 0
Water heat elec share	0 0	0 0	0 0	2.01 -2.01	0 0	0 0	0 0	0 0	0 0	0 0
Water heat elec effic	0 0	0 0	0 0	-1.83 2.23	0 0	0 0	0 0	0 0	0 0	0 0
Cooking elec share	-0.08 0.08	-0.07 0.07	-0.07 0.07	0.29 -0.29	-0.07 0.07	-0.07 0.07	-0.06 0.06	-0.06 0.06	0 0	0 0
Cooking elec effi-ciency	0.07 -0.09	0.06 -0.07	0.07 -0.08	-0.26 0.32	0.06 -0.08	0.06 -0.07	0.06 -0.07	0.05 -0.06	0 0	0 0
Cooking oil share	0.79 -0.79	-0.02 0.02	-0.02 0.02	0 0	-0.02 0.02	0.48 -0.48	-0.02 0.02	-0.02 0.02	0 0	0 0

Cooking oil efficiency	-0.72 0.88	0.02 -0.02	0.02 -0.02	0 0	0.02 -0.025	-0.44 0.54	0.01 -0.02	0.01 -0.02	0 0	0 0
Cooking solid share	-0.02 0.02	0.49 -0.49	-0.02 0.02	0 0	-0.02 0.02	-0.02 0.02	-0.02 0.02	0.33 -0.33	0 0	0 0
Cooking solid effic.	0.02 -0.03	-0.44 0.54	0.02 -0.02	0 0	0.02 -0.02	0.02 -0.02	0.01 -0.02	-0.30 0.36	0 0	0 0
Cooking gas share	-0.43 0.43	-0.33 0.33	-0.37 0.37	-0.06 0.06	-0.02 0.02	-0.34 0.34	-0.31 0.31	-0.29 0.29	0 0	0 0
Cooking gas efficiency	0.39 -0.48	0.30 -0.37	0.34 -0.41	0.06 -0.07	0.02 -0.02	0.31 -0.38	0.28 -0.35	0.27 -0.32	0 0	0 0
Cooking solid share	-0.02 0.02	0.49 -0.49	-0.02 0.02	0 0	-0.02 0.02	-0.02 0.02	-0.02 0.02	0.33 -0.33	0 0	0 0
Cooking solid effic.	0.02 -0.03	-0.44 0.54	0.02 -0.02	0 0	0.02 -0.02	0.02 -0.02	0.01 -0.02	-0.30 0.36	0 0	0 0
Cooking gas share	-0.43 0.43	-0.33 0.33	-0.37 0.37	-0.06 0.06	-0.02 0.02	-0.34 0.34	-0.31 0.31	-0.29 0.29	0 0	0 0
Cooking gas efficiency	0.39 -0.48	0.30 -0.37	0.34 -0.41	0.06 -0.07	0.02 -0.02	0.31 -0.38	0.28 -0.35	0.27 -0.32	0 0	0 0
Water heat CHPDH share	0.19 -0.19	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Water heat CHPDH efficiency	-0.17 0.21	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Space heat CHPDH share	0.23 -0.23	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Space heat CHPDH efficiency	-0.21 0.25	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

Table II-4 continued.

	Total Em [Solid Fuel,Sulphur Dioxide]	Total Em [Solid Fuel,Nitrous Oxides]	Total Em [Solid Fuel,VOC]	Total Em [Solid Fuel,Methane]	Total Em [Solid Fuel,Carbon Monoxide]	Total Em [Solid Fuel,Black Smoke]
Residents	9.78 -9.78	9.78 -9.78	9.78 -9.78	9.78 -9.78	9.78 -9.78	9.78 -9.78
People Per household	-7.95 9.72	-7.95 9.72	-7.95 9.72	-7.95 9.72	-7.95 9.72	-7.95 9.72
Students	0.31 -0.31	0.31 -0.31	0.31 -0.31	0.32 -0.32	0.31 -0.31	0.31 -0.31
Light n App Elec per HH	5.65 -5.65	5.65 -5.65	5.65 -5.65	5.65 -5.65	5.65 -5.65	5.65 -5.65
Hot water temp	3.01 -3.01	3.01 -3.01	3.01 -3.01	3.01 -3.01	3.01 -3.01	3.01 -3.01
Mains temp	-0.43 0.43	-0.43 0.43	-0.43 0.43	-0.43 0.43	0.43 0.43	-0.43 0.43
Floor area	1.86 -1.86	1.86 -1.86	1.86 -1.86	1.87 -1.86	1.86 -1.86	1.86 -1.86
Heat loss par	2.85 -2.76	2.85 -2.76	2.85 -2.76	2.85 -2.76	2.85 -2.76	2.85 -2.76
Cook gains	-0.14 0.14	-0.14 0.14	-0.14 0.14	-0.14 0.14	-0.14 0.14	-0.14 0.14
Internal temp	5.15 -4.26	5.15 -4.26	5.15 -4.26	5.15 -4.26	5.15 -4.26	5.15 -4.26
Light n app gains	-0.29 0.29	-0.29 0.29	-0.29 0.29	-0.29 0.29	-0.29 0.29	-0.29 0.29
Solar gains	-0.63 0.67	-0.63 0.67	-0.63 0.67	-0.63 0.67	-0.63 0.67	-0.63 0.67
Water n metabolic gains	-0.22 0.22	-0.22 0.22	-0.22 0.22	-0.22 0.22	-0.22 0.22	-0.22 0.22

Litres per day	2.58 -2.58	2.58 -2.58	2.58 -2.58	2.58 -2.58	2.58 -2.58	2.58 -2.58
Space oil share	0 0	0 0	0 0	0 0	0 0	0 0
Space oil efficiency	0 0	0 0	0 0	0 0	0 0	0 0
Space elec share	0.64 -0.64	0.64 -0.64	0.64 -0.64	0.64 -0.64	0.64 -0.64	0.64 -0.64
Space elec efficiency	-0.59 0.72	-0.59 0.71	-0.59 0.71	-0.59 0.72	-0.59 0.71	-0.59 0.72
Space gas share	0.09 -0.12	0.09 -0.12	0 0	0 0	0 0	0 0
Space gas efficiency	0 0	0 0	0 0	0 0	0 0	0 0
Space solid share	0 0	0 0	0.87 -0.87	0.87 -0.87	0.87 -0.87	0.87 -0.87
Space solid efficiency	0 0	0.89 -0.89	-0.79 0.96	-0.79 0.96	-0.79 0.96	-0.79 0.96
Water heat oil share	0 0	0.89 -0.89	0 0	0 0	0 0	0 0
Water heat oil efficiency	1.67 -1.67	0 0	0 0	0 0	0 0	0 0
Water heat gas share	-1.52 1.85	0 0	0 0	0 0	0 0	0 0
Water heat gas effic.	0 0	0 0	0 0	0 0	0 0	0 0
Water heat solid share	0 0	0 0	0.83 -0.83	0.83 -0.83	0.83 -0.83	0.83 -0.83
Water heat solid effic.	0.62 -0.62	1.48 -1.48	-0.76 0.93	-0.76 0.93	-0.76 0.93	-0.76 0.93
Water heat elec share	-0.57 0.69	-1.34 1.64	1.74 -1.74	1.74 -1.74	1.74 -1.74	1.74 -1.74

Water heat elec effic	0.03 -0.03	0.20 -0.20	-1.59 1.94	-1.59 1.94	-1.59 1.94	-1.59 1.94
Cooking elec share	-0.03 0.03	-0.12 0.21	0.25 -0.25	0.25 -0.25	0.25 -0.25	0.25 -0.25
Cooking elec efficiency	-0.02 0.02	0.24 -0.24	-0.23 0.28	-0.23 0.28	-0.23 0.28	-0.23 0.28
Cooking oil share	0.02 -0.02	-0.22 0.27	-0.01 0.01	-0.01 0.01	-0.01 0.01	-0.01 0.01
Cooking oil efficiency	-0.02 0.02	-0.01 0.01	0.01 -0.01	0 -0.01	0 -0.01	0.01 -0.01
Cooking solid share	0.02 -0.02	0.01 -0.01	0.08 -0.08	0.08 -0.08	0.08 -0.08	0.08 -0.08
Cooking solid effic.	0.04 -0.04	-0.17 0.17	-0.08 0.09	-0.08 0.09	-0.08 0.09	-0.08 0.09
Cooking gas share	-0.04 0.05	0.15 -0.19	-0.10 0.10	-0.10 0.10	-0.10 0.10	-0.10 0.10
Cooking gas efficiency	0.09 -0.12	0.09 -0.12	0 0	0 0	0 0	0 0
Water heat CHPDH share	0 0	0 0	0 0	0 0	0 0	0 0
Water heat CHPDH efficiency	0 0	0 0	0 0	0 0	0 0	0 0
Space heat CHPDH share	0 0	0 0	0 0	0 0	0 0	0 0
Space heat CHPDH efficiency	0 0	0 0	0 0	0 0	0 0	0 0

A level of change to an output of four percent or more was considered to be significant. This procedure allowed the identification of a sub set of input variables to which the model was most sensitive.

Results of the preliminary stage for non renewable input variables indicated that the most significant variables for the model were the number of residents, the number of people per household, the heat loss parameter, the internal temperature and the floor area. A significance of more than four percent was also achieved by twelve secondary variables. These variables only significantly affected outputs that related to the same fuel type, whereas the most significant, primary variables affect the majority of output parameters.

II.1.2.1 Results: non renewable input variables which DREAM was most sensitive to

- Number of residents.
- Number of people per household.
- Heat loss parameter.
- Internal temperature.
- Floor area.

II.1.3 Sensitivity analysis for input variables relating to renewables

Since the provided DREAM model scenario was a business as usual case, there was no contribution to electricity generation from local renewable energy sources. In order to investigate the sensitivity of the model to renewable energy related input variables, it was therefore necessary to develop a new base case scenario for comparison. The values of variables in the new base case are shown in Table II-5. Alterations in these input variables achieved a 4.5 percent decrease in annual fossil fuel use by month 504, due to increased use of renewable sources.

Table II-5 Input values for renewable input variables for the base case scenario

Month number	Number of turbines
0	0
48	0
96	0
144	0
192	20
240	20
288	60
336	100
384	140
432	200
480	200
528	200
Month number	Percentage of south facing roofs with PV
0	0.00
192	0.05
384	0.10
576	0.20
Month number	Hydro installed
0	0
192	1,500
384	4,000
576	8,000
Month number	Size of CHP installed
0-120	0
132	160
144	400
156	626
168	986
180	1300
192	1550
204	1850
216-504	2000
Month number	Biomass supply to boilers
	0
0	0.5
192	0.5
384	0.5
576	
Month number	Biomass supply to CHP
	0
0	0.5
192	0.5
384	0.5
576	

The base case, plus ten percent, and minus ten percent values for all renewable input variables are shown in Table II-6. These variables were investigated and the effect on output variables was evaluated. The full results of this sensitivity analysis are shown in Table II-7.

Table II-6 Variations in renewable input variables

Variable	Base case value	+10% value	-10% value
Wind speed data			
1	5.74	6.314	5.166
2	5.04	5.544	4.536
3	5.48	6.028	4.932
4	4.97	5.467	4.473
5	4.7	5.17	4.23
6	4.41	4.851	3.969
7	4.15	4.565	3.735
8	4.04	4.444	3.636
9	4.72	5.192	4.248
10	4.71	5.181	4.239
11	5.58	6.138	5.022
12	5.92	6.512	5.328
Number of turbines			
0	0	0	0
48	0	0	0
96	0	0	0
144	0	0	0
192	20	22	18
240	20	22	18
288	60	66	54
336	100	110	90
384	140	154	126
432	200	220	180
480	200	220	180
528	200	220	180
Annual mean wind speed	2.89	3.179	2.601
Turbine CoP			
0	0.3	0.33	0.27
192	0.3	0.33	0.27
384	0.3	0.33	0.27
576	0.3	0.33	0.27
Turbine diameter	30	33	27
Array efficiency			
0	0.9	0.99	0.81
192	0.9	0.99	0.81
384	0.9	0.99	0.81
576	0.9	0.99	0.81

Area of roofs south facing 0 192 384 576	 882,000 1,400,000 1,900,000 2,401,000	 970,200 1,540,000 2,090,000 2,641,100	 793,800 1,260,000 1,710,000 2,160,900
Percentage of south facing roofs suitable for PV	0.5	0.55	0.45
Percentage of south facing roofs with PV 0 192 384 576	 0 0.05 0.10 0.20	 0 0.055 0.11 0.22	 0 0.045 0.09 0.18
Module efficiency 0 25 50 75 100 125 150 175 200 225 250 275 300	 0.1 0.106 0.11 0.114 0.119 0.124 0.129 0.132 0.138 0.141 0.147 0.153 0.160	 0.11 0.1166 0.121 0.1254 0.1309 0.1364 0.1419 0.1452 0.1518 0.1551 0.1617 0.1683 0.176	 0.09 0.0954 0.099 0.1026 0.1071 0.1116 0.1161 0.1188 0.1242 0.1269 0.1323 0.1377 0.144
Inverter efficiency	0.9	0.99	0.81
Peak rainfall	300	330	270
Hydro installed 0 192 384 576	 0 1,500 4,000 8,000	 0 1,650 4,400 8,800	 0 1,350 3,600 7,200
Size of CHP 0-120 132 144 156 168 180 192 204 216 228-504	 0 160 400 626 986 1300 1550 1850 2000 2000	 0 176 440 688.6 1084.6 1430 1705 2035 2200 2200	 0 144 360 563.4 887.4 1170 1395 1665 1800 1800

Bio supply to boilers 0 192 384 576	 0 0.5 0.5 0.5	 0 0.55 0.55 0.55	 0 0.45 0.45 0.45
Biomass supply to CHP 0 192 384 576	 0 0.5 0.5 0.5	 0 0.55 0.55 0.55	 0 0.45 0.45 0.45
Grid transmission losses	0.1	0.11	0.09

Table II-7 Full results of +10%/-10% sensitivity analysis for renewable input variables. Figures shown are the percentage changes in output from the base case, to two decimal places, with the first figure resulting from a +10% change in the input and the second figure from a -10% change in the input

	Annual roll elec	Annual roll gas	Annual roll oil	Annual roll solid	Annual roll CHPDH	Mthly grid elec	Mthly gas	Mthly oil	Mthly CHPDH	Mthly solid
Wind speed data	0 0	0 0	0 0	0 0	0 0	-0.89 0.76	0 0	0 0	0 0	0 0
Number of turbines	0 0	0 0	0 0	0 0	0 0	-0.34 0.34	0 0	0 0	0 0	0 0
Annual mean wind speed	0 0	0 0	0 0	0 0	0 0	-0.90 0.76	0 0	0 0	0 0	0 0
Turbine CoP	0 0	0 0	0 0	0 0	0 0	-0.34 0.34	0 0	0 0	0 0	0 0
Turbine diameter	0 0	0 0	0 0	0 0	0 0	-0.72 0.65	0 0	0 0	0 0	0 0
Array efficiency	0 0	0 0	0 0	0 0	0 0	-0.34 0.34	0 0	0 0	0 0	0 0
Area of roofs south facing	0 0	0 0	0 0	0 0	0 0	-0.12 0.12	0 0	0 0	0 0	0 0
Percentage of south facing roofs suitable for PV	0 0	0 0	0 0	0 0	0 0	-0.12 0.12	0 0	0 0	0 0	0 0

Percentage of south facing roofs with PV	0 0	0 0	0 0	0 0	0 0	-0.12 0.12	0 0	0 0	0 0	0 0
Module efficiency	0 0	0 0	0 0	0 0	0 0	-0.12 0.12	0 0	0 0	0 0	0 0
Inverter efficiency	0 0	0 0	0 0	0 0	0 0	-0.12 0.12	0 0	0 0	0 0	0 0
Peak rainfall	0 0	0 0	0 0	0 0	0 0	0.17 -0.21	0 0	0 0	0 0	0 0
Hydro installed	0 0	0 0	0 0	0 0	0 0	-0.19 0.19	0 0	0 0	0 0	0 0
Size of CHP	0 0	0 0	0 0	0 0	0 0	-0.11 0.11	0 0	0 0	0 0	0 0
Bio supply to boilers	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Biomass supply to CHP	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Grid transmission losses	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

Table II-7 continued.

	Mthly PV	Mthly wind	Mthly hydro	Mthly total biomass	Total households	Total population	Total FF gas	Total FF oil	Total FF solid fuel
Wind speed data	0 0	28.24 -23.72	0 0	0 0	0 0	0 0	-0.20 0.17	-0.49 0.40	-0.58 0.48
Number of turbines	0 0	10.00 -10.00	0 0	0 0	0 0	0 0	-0.07 0.07	-0.16 0.16	-0.19 0.19
Annual mean wind speed	0 0	28.24 -23.72	0 0	0 0	0 0	0 0	-0.20 0.17	-0.49 0.40	-0.58 0.48
Turbine CoP	0 0	10.00 -10.00	0 0	0 0	0 0	0 0	-0.07 0.07	-0.16 0.16	-0.19 0.19
Turbine diameter	0 0	21.00 -19.00	0 0	0 0	0 0	0 0	-0.14 0.13	-0.34 0.30	-0.40 0.36
Array efficiency	0 0	10.00 -10.00	0 0	0 0	0 0	0 0	-0.07 0.13	-0.16 0.30	-0.19 0.36
Area of roofs south facing	10.00 -10.00	0 0	0 0	0 0	0 0	0 0	-0.04 0.04	-0.10 0.10	-0.11 0.11
Percentage of south facing roofs suitable for PV	10.01 -10.01	0 0	0 0	0 0	0 0	0 0	-0.04 0.04	-0.10 0.10	-0.11 0.11
Percentage of south facing roofs with PV	10.01 -10.01	0 0	0 0	0 0	0 0	0 0	-0.04 0.04	-0.10 0.10	-0.11 0.11
Module efficiency	10.01 -10.01	0 0	0 0	0 0	0 0	0 0	-0.04 0.04	-0.10 0.10	-0.11 0.11
Inverter efficiency	10.01 -10.01	0 0	0 0	0 0	0 0	0 0	-0.04 0.04	-0.10 0.10	-0.11 0.11
Peak rainfall	0 0	0 0	-9.09 11.12	0 0	0 0	0 0	0.05 -0.07	0.13 -0.16	0.16 -0.19
Hydro installed	0 0	0 0	10.00 -10.00	0 0	0 0	0 0	-0.06 0.06	-0.15 0.15	-0.17 0.17
Size of CHP	0 0	0 0	0 0	0 0	0 0	0 0	-0.03 0.03	-0.08 0.08	-0.10 0.10
Bio supply to boilers	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

Biomass supply to CHP	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Grid transmission losses	0 0	0 0	0 0	0 0	0 0	0 0	0.32 -0.31	0.77 -0.75	0.91 -0.89

Table II-7 continued.

	Annual total biomass	Total Em [Gas, Carbon Dioxide]	Total Em [Gas, Sulphur Dioxide]	Total Em [Gas, Nitrous Oxides]	Total Em [Gas, VOC]	Total Em [Gas, Methane]	Total Em [Gas, Carbon Monoxide]	Total Em [Gas, Black Smoke]	Total Em [Oil, Carbon Dioxide]	Total Em [Oil, Sulphur Dioxide]
Wind speed data	0 0	-0.20 0.17	0 0	-0.20 0.17	-0.20 0.17	-0.20 0.17	-0.20 0.17	0 0	-0.49 0.40	-0.49 0.40
Number of turbines	0 0	-0.07 0.07	0 0	-0.07 0.07	-0.07 0.07	-0.07 0.07	-0.07 0.07	0 0	-0.16 0.16	-0.16 0.16
Annual mean wind speed	0 0	-0.20 0.17	0 0	-0.20 0.17	-0.20 0.17	-0.20 0.17	-0.20 0.17	0 0	-0.49 0.40	-0.49 0.40
Turbine CoP	0 0	-0.07 0.07	0 0	-0.07 0.07	-0.07 0.07	-0.07 0.07	-0.07 0.07	0 0	-0.16 0.16	-0.16 0.16
Turbine diameter	0 0	-0.14 0.13	0 0	-0.14 0.13	-0.14 0.13	-0.14 0.12	-0.14 0.13	0 0	-0.34 0.30	-0.34 0.30
Array efficiency	0 0	-0.07 0.13	0 0	-0.07 0.13	-0.07 0.13	-0.07 0.12	-0.07 0.13	0 0	-0.16 0.30	-0.16 0.30
Area of roofs south facing	0 0	-0.04 0.04	0 0	-0.04 0.04	-0.04 0.04	-0.04 0.04	-0.04 0.04	0 0	-0.10 0.10	-0.10 0.10
Percentage of south facing roofs suitable for PV	0 0	-0.04 0.04	0 0	-0.04 0.04	-0.04 0.04	-0.04 0.04	-0.04 0.04	0 0	-0.10 0.10	-0.10 0.10
Percentage of south facing roofs with PV	0 0	-0.04 0.04	0 0	-0.04 0.04	-0.04 0.04	-0.04 0.04	-0.04 0.04	0 0	-0.10 0.10	-0.10 0.10
Module efficiency	0 0	-0.04 0.04	0 0	-0.04 0.04	-0.04 0.04	-0.04 0.04	-0.04 0.04	0 0	-0.10 0.10	-0.10 0.10

Inverter efficiency	0 0	-0.04 0.04	0 0	-0.04 0.04	-0.04 0.04	-0.04 0.04	-0.04 0.04	0 0	-0.10 0.10	-0.10 0.10
Peak rainfall	0 0	0.05 -0.07	0 0	0.05 -0.07	0.05 -0.07	0.05 -0.07	0.05 -0.07	0 0	0.13 -0.16	0.13 -0.16
Hydro installed	0 0	-0.06 0.06	0 0	-0.06 0.06	-0.06 0.06	-0.06 0.06	-0.06 0.06	0 0	-0.15 0.15	-0.15 0.15
Size of CHP	0 0	-0.03 0.03	0 0	-0.03 0.03	-0.03 0.03	-0.03 0.03	-0.03 0.03	0 0	-0.08 0.08	-0.08 0.08
Bio supply to boilers	8.33 -8.33	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Biomass supply to CHP	8.33 -8.33	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Grid transmission losses	0 0	0.32 -0.31	0 0	0.32 -0.31	0.32 -0.31	0.32 -0.31	0.32 -0.31	0 0	0.77 -0.75	0.77 -0.75

Table II-7 continued.

	Total Em [Oil, Nitrous Oxides]	Total Em [Oil, VOC]	Total Em [Oil, Methane]	Total Em [Oil, Carbon Monoxide]	Total Em [Oil, Black Smoke]	Total Em [Solid Fuel, Carbon Dioxide]	Total Em [Solid Fuel, Sulphur Dioxide]	Total Em [Solid Fuel, Nitrous Oxides]	Total Em [Solid Fuel, VOC]
Wind speed data	-0.49 0.40	-0.49 0.40	-0.49 0.40	-0.49 0.40	-0.49 0.41	-0.58 0.48	-0.58 0.48	-0.58 0.48	-0.58 0.48
Number of turbines	-0.16 0.16	-0.14 0.17	-0.14 0.17	-0.16 0.16	-0.16 0.16	-0.19 0.19	-0.19 0.19	-0.19 0.19	-0.19 0.19
Annual mean wind speed	-0.49 0.40	-0.49 0.40	-0.49 0.40	-0.49 0.41	-0.49 0.41	-0.58 0.48	-0.58 0.48	-0.58 0.48	-0.58 0.48
Turbine CoP	-0.16 0.16	-0.14 0.17	-0.14 0.17	-0.16 0.16	-0.16 0.16	-0.19 0.19	-0.19 0.19	-0.19 0.19	-0.19 0.19
Turbine diameter	-0.33 0.30	-0.34 0.31	-0.34 0.31	-0.33 0.31	-0.34 0.30	-0.40 0.36	-0.40 0.36	-0.40 0.36	-0.40 0.36
Array efficiency	-0.16 0.30	-0.14 0.31	-0.14 0.31	-0.16 0.31	-0.16 0.30	-0.19 0.36	-0.19 0.36	-0.19 0.36	-0.19 0.36

Area of roofs south facing	-0.10 0.10	-0.09 0.11	-0.09 0.11	-0.09 0.10	-0.09 0.10	-0.11 0.11	-0.11 0.11	-0.11 0.11	-0.11 0.12
Percentage of south facing roofs suitable for PV	-0.10 0.10	-0.09 0.11	-0.09 0.11	-0.09 0.10	-0.09 0.10	-0.11 0.11	-0.11 0.11	-0.11 0.11	-0.11 0.12
Percentage of south facing roofs with PV	-0.10 0.10	-0.09 0.11	-0.09 0.11	-0.09 0.10	-0.09 0.10	-0.11 0.11	-0.11 0.11	-0.11 0.11	-0.11 0.12
Module efficiency	-0.10 0.10	-0.09 0.11	-0.09 0.11	-0.09 0.10	-0.09 0.10	-0.11 0.11	-0.11 0.11	-0.11 0.11	-0.11 0.12
Inverter efficiency	-0.10 0.10	-0.09 0.11	-0.09 0.11	-0.09 0.10	-0.09 0.10	-0.11 0.11	-0.11 0.11	-0.11 0.12	-0.11 0.12
Peak rainfall	0.13 -0.16	0.14 -0.14	0.14 -0.14	0.13 -0.16	0.13 -0.16	0.16 -0.19	0.16 -0.19	0.16 -0.19	0.16 -0.19
Hydro installed	-0.14 0.15	-0.14 0.14	-0.14 0.14	-0.14 0.14	-0.14 0.15	-0.17 0.17	-0.17 0.17	-0.17 0.17	-0.17 0.17
Size of CHP	-0.08 0.08	-0.09 0.09	-0.09 0.09	-0.08 0.09	-0.08 0.09	-0.10 0.10	-0.10 0.10	-0.10 0.10	-0.10 0.10
Bio supply to boilers	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Biomass supply to CHP	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Grid transmission losses	0.77 -0.75	0.77 -0.74	0.77 -0.74	0.77 -0.75	0.77 -0.75	0.91 -0.89	0.91 -0.89	0.91 -0.89	0.91 -0.89

Table II-7 continued.

	Total Em [Solid Fuel, Methane]	Total Em [Solid Fuel, Carbon Monoxide]	Total Em [Solid Fuel, Black Smoke]
Wind speed data	-0.58 0.48	-0.58 0.48	-0.58 0.48
Number of turbines	-0.19 0.19	-0.19 0.19	-0.19 0.19
Annual mean wind speed	-0.58 0.48	-0.58 0.48	-0.58 0.48
Turbine CoP	-0.19 0.19	-0.19 0.19	-0.19 0.19
Turbine diameter	-0.40 0.36	-0.40 0.36	-0.40 0.36
Array efficiency	-0.19 0.36	-0.19 0.36	-0.19 0.36
Area of roofs south facing	-0.11 0.11	-0.11 0.11	-0.11 0.11
Percentage of south facing roofs suitable for PV	-0.11 0.11	-0.11 0.11	-0.11 0.11
Percentage of south facing roofs with PV	-0.11 0.11	-0.11 0.11	-0.11 0.11
Module efficiency	-0.11 0.11	-0.11 0.11	-0.11 0.11
Inverter efficiency	-0.11 0.11	-0.11 0.11	-0.11 0.11
Peak rainfall	0.16 -0.19	0.16 -0.19	0.16 -0.19

Hydro installed	-0.17 0.17	-0.17 0.17	-0.17 0.17
Size of CHP	-0.10 0.10	-0.10 0.10	-0.10 0.10
Bio supply to boilers	0 0	0 0	0 0
Biomass supply to CHP	0 0	0 0	0 0
Grid transmission losses	0.91 -0.89	0.91 -0.89	0.91 -0.89

Thirty five runs of the model were necessary to complete this preliminary sensitivity analysis. The results indicated that fifteen of the seventeen variables produced a variation in an output variable of more than four percent. However, in every case, the variation in input variable only produced a significant variation in one output variable, relating to the particular renewable energy source. All other output parameters did not show any significant variation (for example the monthly grid electricity supplied never varied more than one percent from the base case level).

Therefore, despite these fifteen variables achieving a significant variation in output parameters, it was not considered that the model was sensitive to these input variables, since in each case only one output variable was significantly affected, and this variable was always related to that particular renewable fuel type.

II.1.4 Defining a group of output variables representative of the model

After determining a suitable sub sector of input variables which the model was most sensitive to, it was necessary (in order to reduce the number of variables under consideration to a manageable level) to also determine a group of output parameters which would be representative of the model. This was done by first listing the changes to all output variables for the five input variables chosen. The percentage changes were then compared and ranked, and the five ranks added together. The total ranking of each output is shown in Table II-8.

Output parameters relating to gas, oil or solid fuel demand (or emissions) showed a sensitivity to the five chosen input variables. Ranking the output parameters in order of their percentage change (following a ten percent change in input variable) indicates that the greatest change occurred in the following ten outputs: monthly gas, monthly oil, annual rolling gas, monthly CHPDH, annual rolling oil, total emissions (gas carbon monoxide), total emissions (gas nitrous oxides), total emissions (gas methane), total emissions (gas carbon dioxide) and total fossil fuel supplied (gas).

From the ranking exercise it was clear that, for the five chosen input variables, gas-related output parameters were most sensitive to change. Five output parameters were chosen from the top ten ranked outputs, and not all were gas-related, to ensure representation of information on other fuel types.

Table II-8 Ranking of the output parameter percentage change for each of the five chosen input variables

	total rank
annual roll CHPDH (Billions)	152.0
annual roll elec (Billions)	288.0
annual roll gas (Billions)	80.0
annual roll oil (Billions)	100.0
annual roll solid (Billions)	200.0
MODEL Mthly CHPDH (Billions)	96.0
MODEL Mthly Gas (Billions)	31.0
MODEL Mthly Oil (Billions)	47.0
MODEL Mthly Solid (Billions)	132.0
Mthly Grid Elec (Billions)	274.0
Total Emissions[Gas,Carbon Dioxide]	121.0
Total Emissions[Gas,Carbon Monoxide]	107.0
Total Emissions[Gas,Methane]	117.5
Total Emissions[Gas,Nitrous Oxides]	122.5
Total Emissions[Gas,VOC]	107.0
Total Emissions[Oil,Black Smoke]	177.0
Total Emissions[Oil,Carbon Dioxide]	174.5
Total Emissions[Oil,Carbon Monoxide]	178.0
Total Emissions[Oil,Methane]	177.0
Total Emissions[Oil,Nitrous Oxides]	182.0
Total Emissions[Oil,Sulphur Dioxide]	176.0
Total Emissions[Oil,VOC]	177.0
Total Emissions[Solid Fuel,Black Smoke]	220.5
Total Emissions[Solid Fuel,Carbon Dioxide]	225.5
Total Emissions[Solid Fuel,Carbon Monoxide]	223.5
Total Emissions[Solid Fuel,Methane]	231.5
Total Emissions[Solid Fuel,Nitrous Oxides]	233.0
Total Emissions[Solid Fuel,Sulphur Dioxide]	229.0
Total Emissions[Solid Fuel,VOC]	243.5

Total FF Supplied[Gas]	121.0
Total FF Supplied[Oil]	174.5
Total FF Supplied[Solid Fuel]	225.5
Total Households	270.0
Total Population	336.0

Output parameters chosen as representative of the model

- Monthly gas.
- Monthly oil.
- Monthly CHPDH.
- Annual rolling oil.
- Total emissions (gas carbon monoxide).

II.1.5 Further investigation of the sensitivity of the model to single variables

For each of the five input variables identified in the preliminary analysis, a more detailed investigation of the model sensitivity was carried out. Each input variable was altered within the range of plus ten percent and minus ten percent, in two percent increments. This meant a further forty runs of the model. Results are shown in Table II-9 and they clearly indicate that the percentage change in outputs was linear with the change in input, for all five variables investigated. The results are shown graphically in Figure II-6 to Figure II-11.

Table II-9 Sensitivity results for the most significant input variables, using chosen comparison output variables

Residents					
Variation in input	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions (gas CO)
10%	9.98	9.98	9.98	9.66	9.70
8%	7.99	7.99	7.99	7.73	7.76
6%	5.99	5.99	5.99	5.80	5.82
4%	3.99	3.99	3.99	3.86	3.88
2%	2.00	2.00	2.00	1.93	1.94
0	0.00	0.00	0.00	0.00	0.00
-2%	-2.00	-2.00	-2.00	-1.93	-1.94
-4%	-3.99	-3.99	-3.99	-3.86	-3.88
-6%	-5.99	-5.99	-5.99	-5.80	-5.82
-8%	-7.99	-7.99	-7.99	-7.73	-7.76
-10%	-9.98	-9.98	-9.98	-9.66	-9.70
People per household					
Variation in input	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions (gas CO)
10%	-8.90	-8.70	-8.02	-8.24	-8.37
8%	-7.25	-7.09	-6.54	-6.71	-6.82
6%	-5.54	-5.42	-5.00	-5.13	-5.21
4%	-3.77	-3.68	-3.39	-3.48	-3.54
2%	-1.92	-1.88	-1.73	-1.78	-1.80
0	0.00	0.00	0.00	0.00	0.00

-2%	2.00	1.95	1.80	1.85	1.88
-4%	4.08	3.99	3.68	3.78	3.83
-6%	6.25	6.11	5.63	5.78	5.87
-8%	8.51	8.32	7.67	7.88	8.00
-10%	10.88	10.63	9.81	10.07	10.23
Heat loss parameter					
Variation in input	**monthly gas**	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
10%	11.40	10.75	9.84	11.82	9.54
8%	9.12	8.60	7.87	9.44	7.61
6%	6.85	6.46	5.91	7.07	5.70
4%	4.56	4.30	3.93	4.67	3.77
2%	2.28	2.15	1.97	2.32	1.87
0	0.00	0.00	0.00	0.00	0.00
-2%	-2.28	-2.15	-1.97	-2.31	-1.86
-4%	-4.56	-4.30	-3.94	-4.62	-3.72
-6%	-6.84	-6.45	-5.90	-6.92	-5.58
-8%	-9.12	-8.60	-7.87	-9.21	-7.43
-10%	-11.40	-10.75	-9.84	-11.44	-9.22
Internal temperature					
Variation in input	**monthly gas**	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
10%	14.85	14.00	12.81	21.34	17.22
8%	11.88	11.20	10.25	16.80	13.55
6%	8.91	8.40	7.69	12.38	9.99

4%	5.94	5.60	5.13	8.10	6.54
2%	2.97	2.80	2.56	3.99	3.22
0	0.00	0.00	0.00	0.00	0.00
-2%	-2.97	-2.80	-2.56	-3.85	-3.10
-4%	-5.94	-5.60	-5.13	-7.53	-6.07
-6%	-8.91	-8.40	-7.69	-11.02	-8.89
-8%	-11.88	-11.20	-10.25	-14.40	-11.62
-10%	-14.85	-14.00	-12.81	-17.64	-14.23
Floor area					
Variation in input	**monthly gas**	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
10%	9.41	8.87	8.12	7.72	6.23
8%	7.53	7.10	6.50	6.17	4.98
6%	5.65	5.32	4.87	4.63	3.73
4%	3.76	3.55	3.25	3.08	2.49
2%	1.88	1.77	1.62	1.54	1.24
0	0.00	0.00	0.00	0.00	0.00
-2%	-1.88	-1.77	-1.63	-1.54	-1.24
-4%	-3.76	-3.55	-3.25	-3.08	-2.49
-6%	-5.65	-5.32	-4.87	-4.63	-3.73
-8%	-7.53	-7.10	-6.50	-6.17	-4.97
-10%	-9.41	-8.87	-8.12	-7.71	-6.22

These results were significant, in that they clearly demonstrated a linear relationship between input variables and output parameters. Therefore, for the input parameters investigated, it would be possible to estimate the direction and magnitude of a change in one of the representative output variables for a given change to a single input variable.

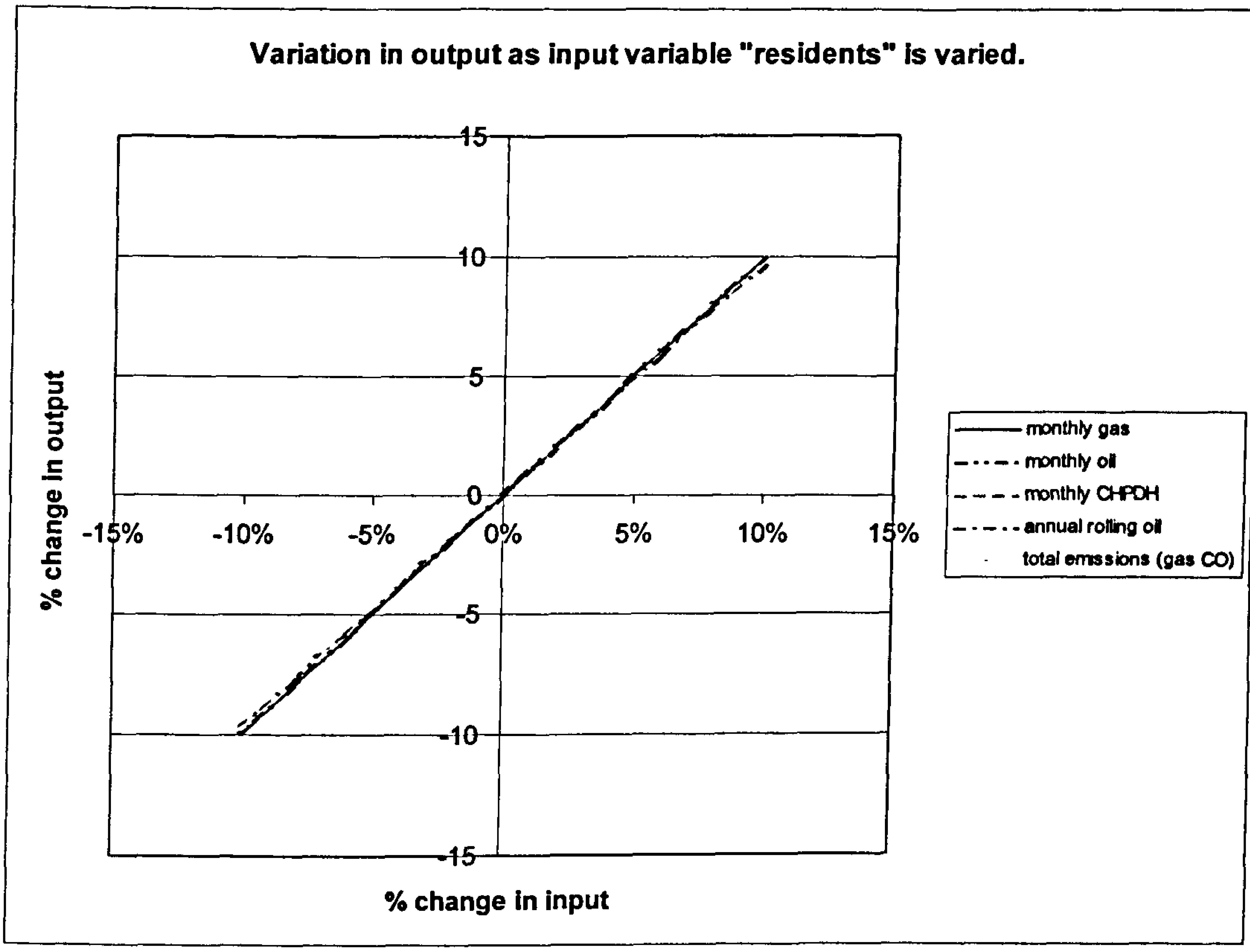

Figure II-6 Variation in output parameters as the input variable "residents" is altered in 2% increments

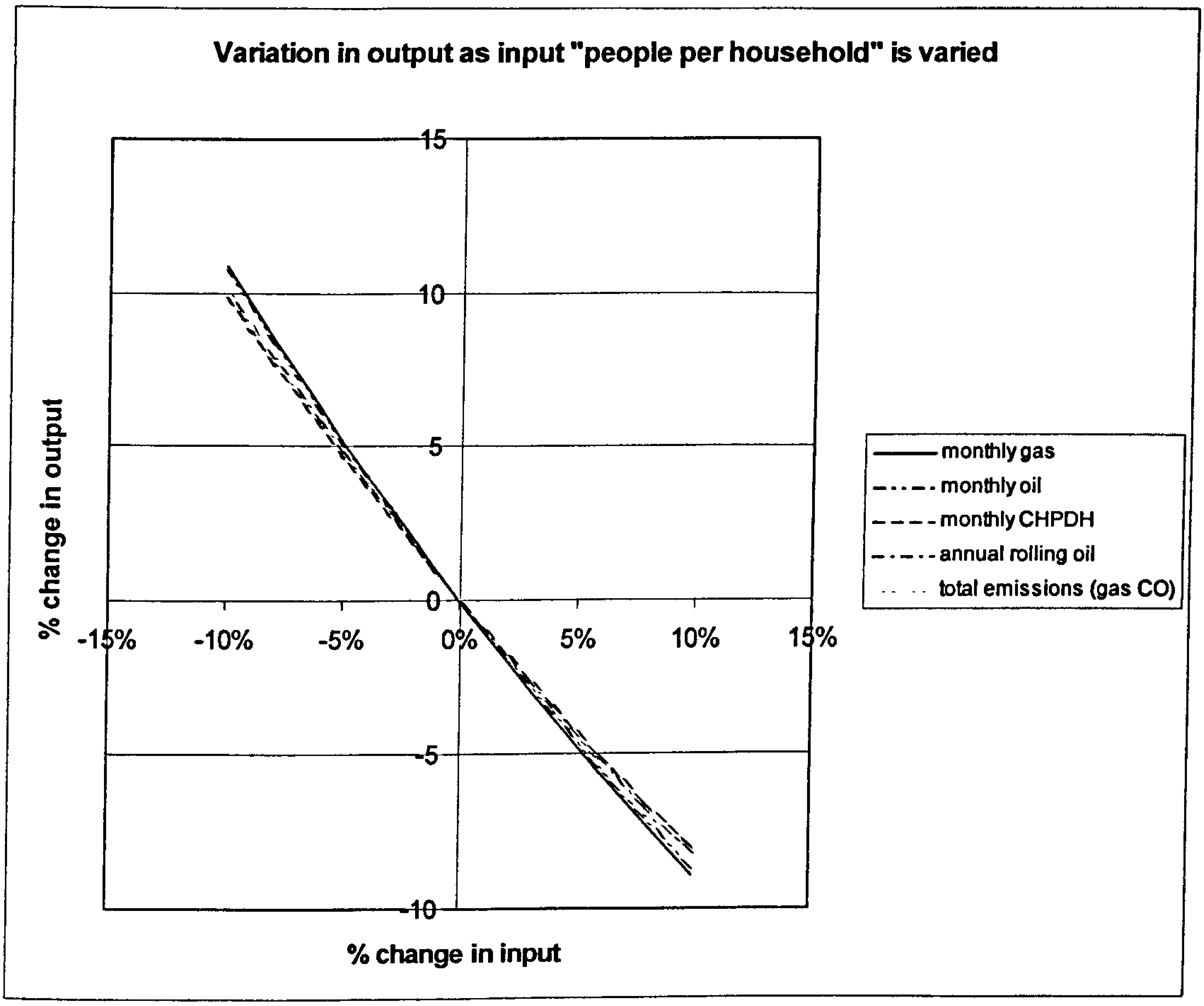

Figure II-7 Variation in output parameters as the input variable "people per household" is altered in 2% increments

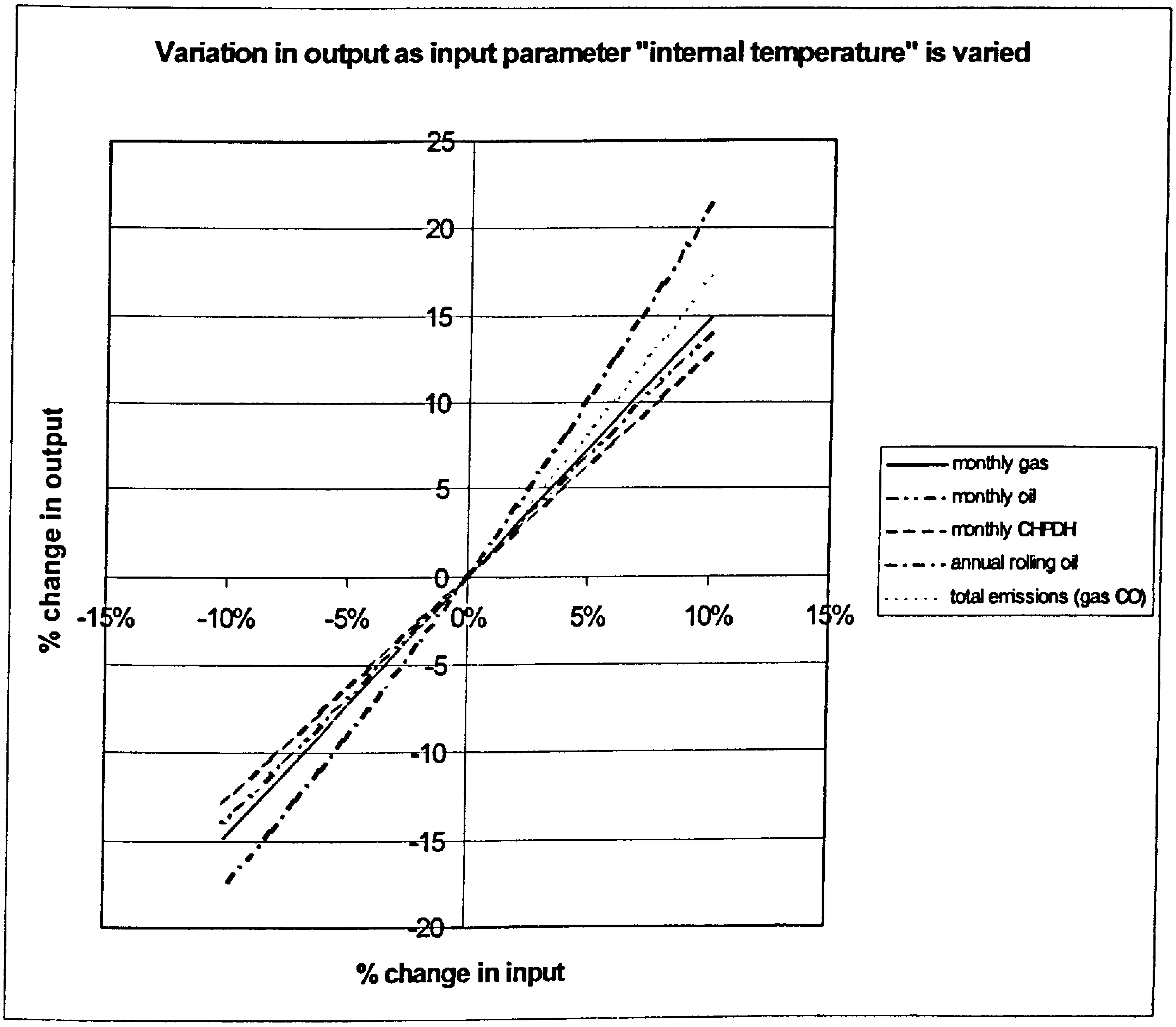

Figure II-8 Variation in output parameters as the input variable "internal temperature" is altered in 2% increments

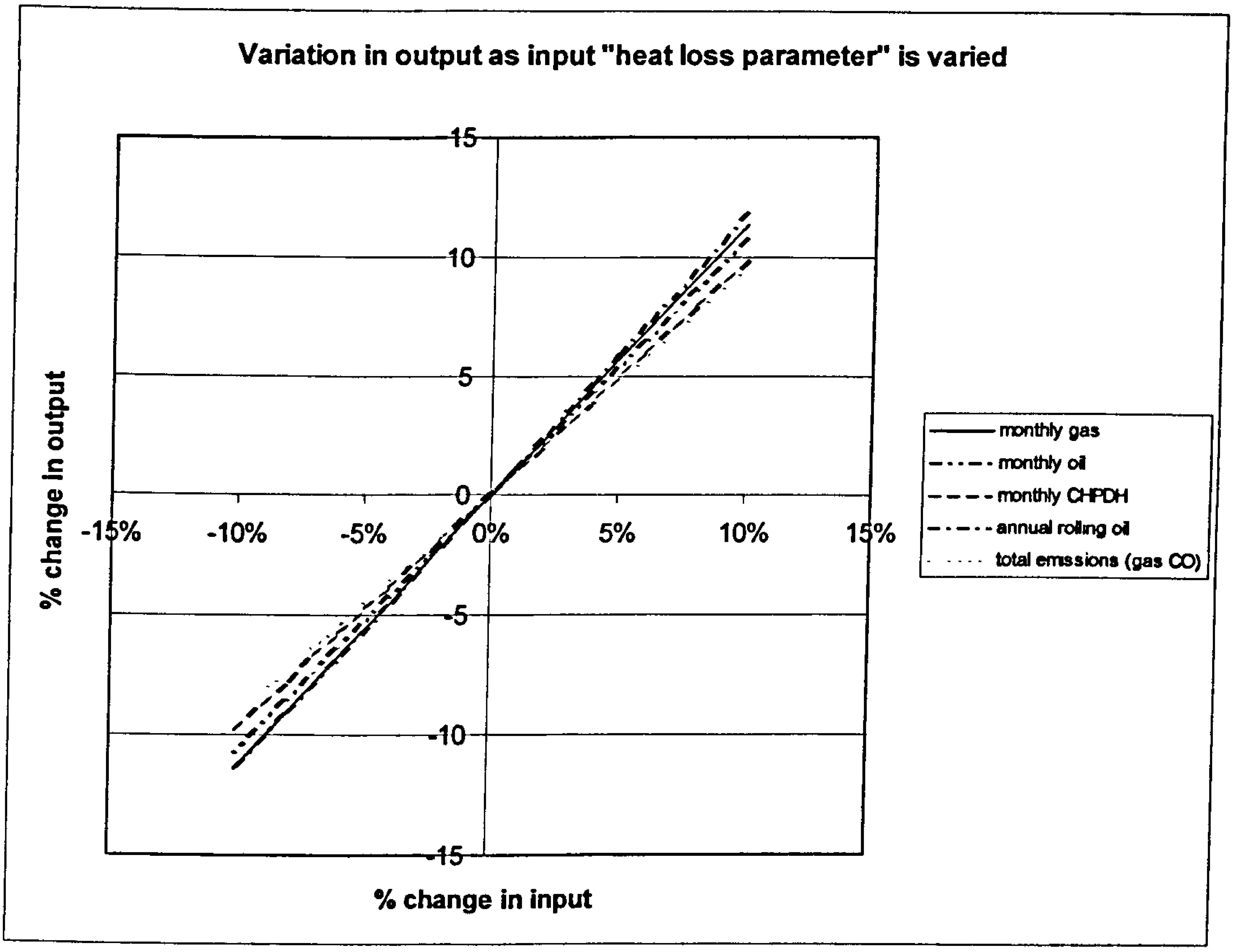

Figure II-9 Variation in output parameters as the input variable "heat loss parameter" is altered in 2% increments

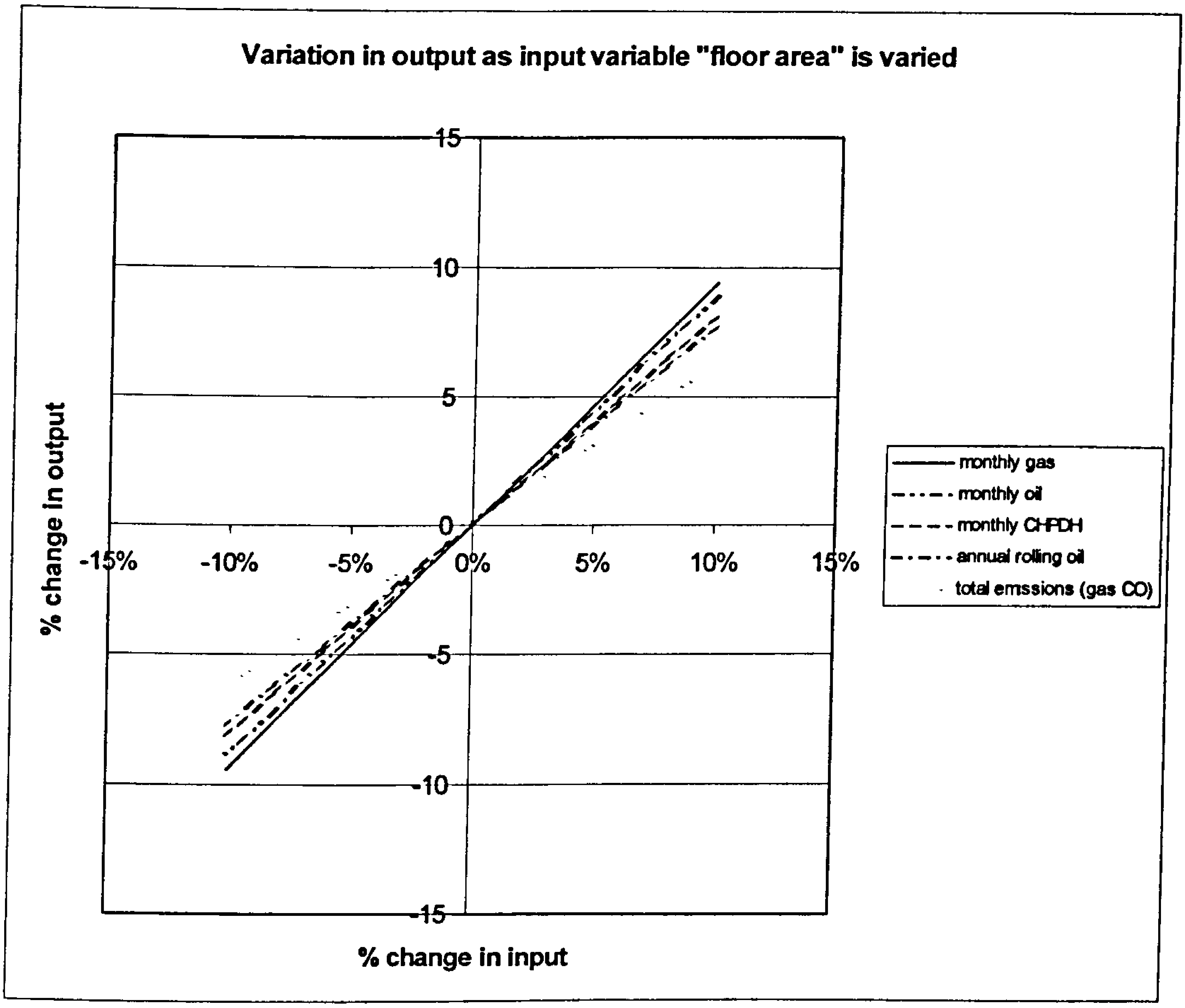

Figure II-10 Variation in output parameters as the input variable "floor area" is altered in 2% increments

II.1.6 Sensitivity to the model of a combination of variables

A logical progression within the sensitivity analysis was to consider the effect of varying more than one variable. There are five variables under investigation, and there are a potential ten combinations of two variables, ten combinations of three variables, five combinations of four variables and one combination of five variables.

The two variable combinations were investigated first. For each variable pair, a combination of positive and negative ten percent increments was investigated. With four possible increment combinations for each pair, and ten possible pairs, it was necessary to complete forty runs of the model. A full set of results for combinations of two input variables is shown in Table II-10.

Since there was such a potentially large number of future increment combinations for the three variable (eight combinations per trio), four variable (sixteen combinations per quad) and five variable (thirty two) combinations, it was necessary to determine whether all increment combinations would need to be investigated.

Therefore, during the two variable investigation, the percentage change in outputs as a result of the pair was compared with the sum of the percentage changes for the individual variables. A good correlation was evident between the sum of individual sensitivity and combined sensitivity, as shown in Figure II-11 for one example pairing. Therefore for any number of input variables, an estimate of the magnitude of change in a representative output variable could be made, if changes to the inputs were know. This meant that not all combinations of input increments required investigation.

When investigating combinations of three, four and five variables only a positive increment of ten percent was added to all input variables. This resulted in a further sixteen runs of the model. In order to confirm the predictability of output parameters, the combined effect of individual input variables was compared with the effect of input variable combinations in each case. These results are shown in Table II-11.

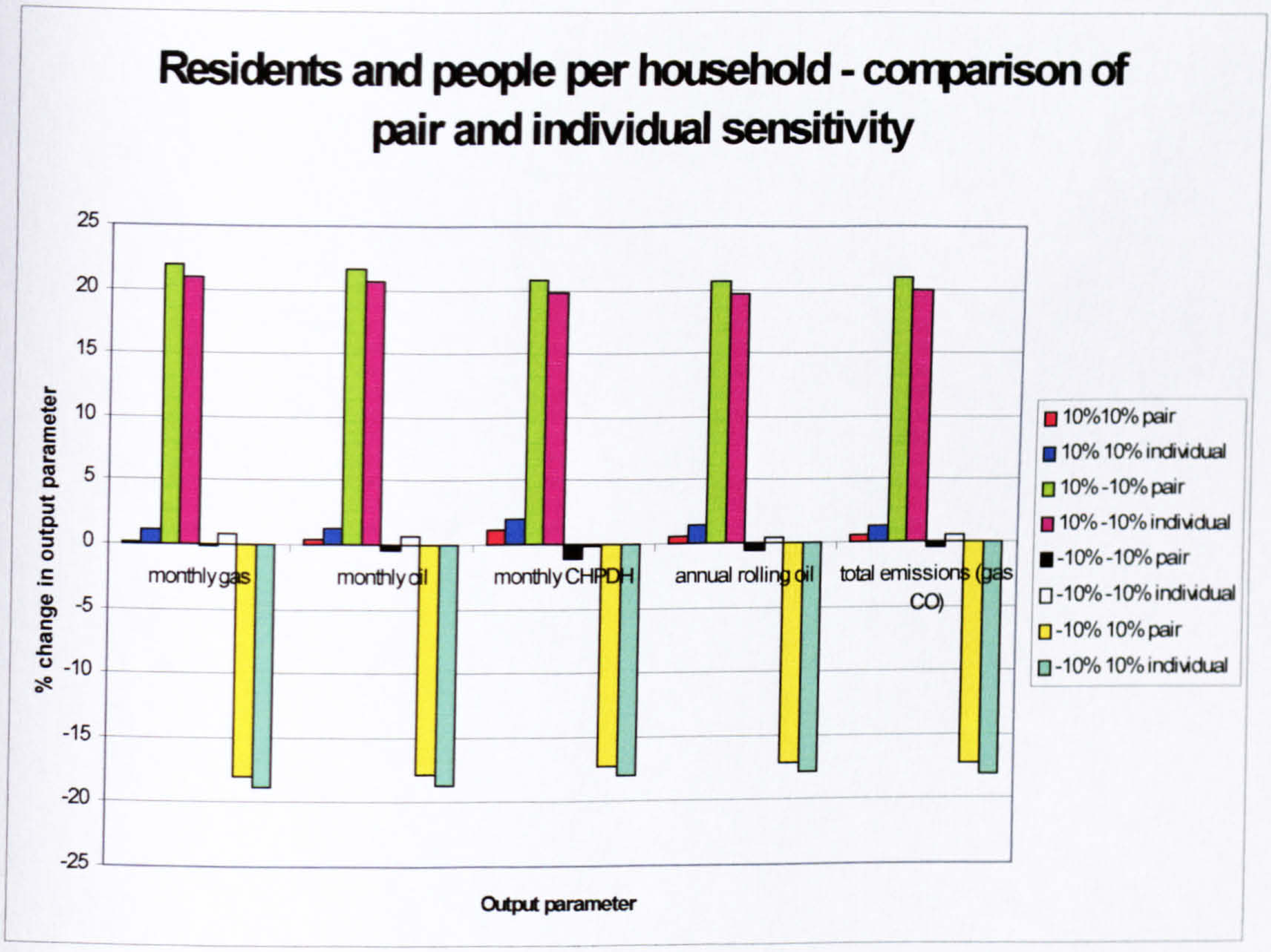

Figure II-11 Comparison of the effect of individual sensitivity and combined sensitivity of two variables - residents and people per household

Table II-10 Sensitivity results for two combinations of input variables

Residents & People per household

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
10%, 10%	0.19	0.42	1.16	0.63	0.53
10%, -10%	21.95	21.68	20.77	20.70	20.91
-10%, -10%	-0.19	-0.42	-1.16	-0.56	-0.46
-10%, 10%	-18.00	-17.81	-17.21	-17.10	-17.26

Residents & Floor area

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
10%, 10%	20.33	19.74	18.92	18.13	16.53
10%, -10%	-0.37	0.23	1.05	1.21	2.88
-10%, -10%	-18.46	-17.97	-17.30	-16.63	-15.32
-10%, 10%	-1.51	-2.00	-2.68	-2.68	-4.07

Residents & Internal temperature

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
10%, 10%	12.73	12.57	12.35	20.27	18.26
10%, -10%	7.24	7.40	7.62	2.79	4.16
-10%, -10%	-12.23	-12.10	-11.92	-15.31	-14.25
-10%, 10%	-7.74	-7.87	-8.05	-0.93	-2.66

Residents & Heat loss parameter

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
10%, 10%	22.52	21.80	20.80	22.62	20.15
10%, -10%	-2.55	-1.84	-0.84	-2.88	-0.42
-10%, -10%	-20.25	-19.66	-18.84	-19.99	-18.03
-10%, 10%	0.28	-0.31	-1.13	1.02	-1.08

People per household & Floor area

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions (gas CO)
10%, 10%	-0.35	-0.63	-0.64	-1.23	-2.71
10%, -10%	-17.46	-16.76	-15.41	-15.25	-14.02
-10%, -10%	0.42	0.77	0.78	1.50	3.32
-10%, 10%	21.34	20.49	18.83	18.67	17.17

People per household & Internal temperature

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions (gas CO)
10%, 10%	4.60	4.03	3.63	11.05	7.19
10%, -10%	-22.40	-21.42	-19.67	-24.13	-21.19
-10%, -10%	-5.62	-4.92	-4.43	-9.69	-5.71
-10%, 10%	27.38	26.18	24.04	33.93	29.47

People per household & Heat loss parameter

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions (gas CO)
10%, 10%	1.46	1.07	0.92	2.47	0.27
10%, -10%	-19.26	-18.47	-16.97	-18.59	-16.72
-10%, -10%	-1.79	-1.31	-1.13	-2.69	-0.06
-10%, 10%	23.55	22.57	20.73	23.25	20.86

Heat loss parameter and internal temperature

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions (gas CO)
10%, 10%	27.73	26.15	23.93	36.60	29.53
10%, -10%	-4.93	-4.65	-4.26	-8.80	-7.10
-10%, -10%	-24.76	-23.35	-21.37	-25.96	-20.94
-10%, 10%	1.96	1.85	1.69	6.62	5.34

Heat loss parameter and floor area

% change	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions (gas CO)

10%, 10%	21.95	20.69	18.94	20.79	16.77
10%, -10%	0.85	0.80	0.73	2.85	2.30
-10%, -10%	-19.67	-18.54	-16.98	-17.90	-14.44
-10%, 10%	-3.13	-2.95	-2.70	-4.95	-3.99
Internal temperature and floor area					
% change	**monthly gas**	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
10%, 10%	25.74	24.27	22.21	31.44	25.36
10%, -10%	3.95	3.73	3.41	11.26	9.09
-10%, -10%	-22.77	-21.47	-19.65	-23.29	-18.79
-10%, 10%	-6.92	-6.53	-5.97	-11.93	-9.62

Table II-11 Sensitivity results for combinations of three, four and five input variables

Residents & People per household & Heat loss parameter					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1573856.00	58284.00	90221.00	417818.00	79483.00
% change	11.59	11.16	11.00	12.37	10.00
predicted change	12.48	12.03	11.80	13.24	10.87
Residents & People per household & Internal temperature					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1622499.00	59989.00	92640.00	452812.00	84968.00
% change	15.04	14.42	13.97	21.78	17.59
predicted change	15.93	15.28	14.77	22.77	18.55
Residents & People per household & Floor area					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1545812.00	57301.00	88826.00	402739.00	77119.00

% change	9.60	9.29	9.28	8.31	6.72
predicted change	10.49	10.16	10.08	9.15	7.56
Residents & Heat loss parameter & Internal temperature					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1981369.00	72744.00	110793.00	557023.00	102668.00
% change	40.49	38.74	36.31	49.81	42.08
predicted change	36.23	34.73	32.63	42.82	36.45
Residents & Heat loss parameter & Floor area					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1891662.00	69599.00	106332.00	492520.00	92557.00
% change	34.13	32.74	30.82	32.46	28.09
predicted change	30.79	29.60	27.94	29.20	25.46
Residents & Internal temperature & Floor area					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1950520.00	71662.00	109259.00	535942.00	99364.00
% change	38.30	36.68	34.42	44.14	37.51
predicted change	34.24	32.86	30.92	38.73	33.15
People per household & Heat loss parameter & Internal temperature					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1640397.00	60333.00	92446.00	464197.00	85495.00
% change	16.31	15.07	13.73	24.84	18.32
predicted change	17.35	16.05	14.63	24.93	18.39
People per household & Heat loss parameter & Floor area					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1566249.00	57734.00	88758.00	411335.00	77208.00

% change	11.05	10.11	9.20	10.62	6.85
predicted change	11.91	10.92	9.93	11.31	7.40

People per household & Internal temperature & Floor area

	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
results	1614899.00	59439.00	91178.00	446989.00	82798.00
% change	14.50	13.37	12.17	20.21	14.58
predicted change	15.36	14.17	12.91	20.83	15.08

Heat loss parameter & Internal temperature & Floor area

	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
results	1973330.00	72162.00	109281.00	551766.00	100466.00
% change	39.92	37.63	34.45	48.39	39.03
predicted change	35.66	33.62	30.77	40.89	32.98

Residents & People per household & Heat loss parameter & Internal temperature

	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
results	1804187	66357	101676	509058	93785
% change	27.92	26.56	25.09	36.91	29.79
predicted change	27.33	26.03	24.61	34.59	28.09

Residents & People per household & Heat loss parameter & Floor area

	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
results	1722636	63499	97620	451066	84694
% change	22.14	21.11	20.10	21.31	17.21
predicted change	21.89	20.91	19.92	20.97	17.10

People per household & Heat loss parameter & Internal temperature & Floor area

	monthly gas	monthly oil	monthly CHPDH	annual rolling oil	total emissions(gas CO)
results	1796612	65808	100215	503975	91730

% change	27.39	25.51	23.29	35.54	26.94
predicted change	26.76	24.92	22.75	32.65	24.62
Residents & Heat loss parameter & Internal temperature & Floor area					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	2170362	79368	120193	605086	110202
% change	53.89	51.38	47.87	62.73	52.51
predicted change	45.64	43.60	40.75	50.55	42.68
Residents & People per household & Internal temperature & Floor area					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1776142	65374	100281	490182	90826
% change	25.94	24.69	23.37	31.83	25.69
predicted change	25.34	24.16	22.89	30.49	24.78
Residents & People per household & Heat loss parameter & Internal temperature & Floor area					
	monthly gas	**monthly oil**	**monthly CHPDH**	**annual rolling oil**	**total emissions (gas CO)**
results	1975999	72379	110221	552677	100622
% change	40.11	38.05	35.60	48.64	39.25
predicted change	36.74	34.90	32.73	42.31	34.32

II.1.7 Conclusions

The DREAM model was most sensitive to internal temperature, heat loss parameter, number of residents, people per household and floor area (in that order). An increase in internal temperature, heat loss parameter, number of residents and floor area all resulted in an increase in energy demand, and hence representative outputs. An increase in the number of people per household led to a reduction in energy demand, and representative outputs.

The change in an output variable was directly proportional to the change in the input variable for internal temperature, heat loss parameter, number of residents and floor area. The change in an output variable was inversely proportional to a change in the number of people per household.

For combinations of variables, the effect was approximately the same as the sum of each variable's individual effect on representative output parameters. These results indicated that the model used logical relationships between variables in order to determine energy demand, and that combinations of input changes had a predictable effect.

II.2 Results of the DREAM scenarios

II.2.1 Wind scenarios to meet tariff demand

Table II-12 Number of turbines required to match green electricity demand for three tariff levels

Month number	Year	Number of turbines		
		2% tariff	8% tariff	15% tariff
0	1984	0	0	0
24	1986	0	0	0
48	1988	0	0	0
72	1990	0	0	0
96	1992	0	0	0
120	1994	0	0	0
144	1996	0	0	0
168	1998	0	0	0
192	2000	0	0	0
216	2002	0	0	0
240	2004	10	10	10
264	2006	20	20	20
288	2008	30	30	30
312	2010	40	40	40
336	2012	60	60	60
360	2014	80	80	60
384	2016	100	80	60
408	2018	115	80	60
432	2020	115	80	68
456	2022	115	80	68
480	2024	115	80	68
504	2026	115	80	68
528	2028	115	80	68
552	2030	115	80	68

Table II-13 Hydro installed required to match green electricity demand for three tariff levels

Month number	Year	Hydro installed (kW)		
		2% tariff	8% tariff	15% tariff
0	1984	0	0	0
24	1986	0	0	0
48	1988	0	0	0
72	1990	0	0	0
96	1992	0	0	0
120	1994	0	0	0
144	1996	0	0	0
168	1998	0	0	0
192	2000	0	0	0
216	2002	0	0	0
240	2004	200	200	200
264	2006	500	500	500
288	2008	1000	1000	1000
312	2010	3000	3000	3000
336	2012	6000	6000	6000
360	2014	10000	10000	10000
384	2016	20000	20000	20000
408	2018	30000	30000	30000
432	2020	50000	50000	40000
456	2022	80000	65000	50000
480	2024	85000	68000	52000
504	2026	85000	68000	52000
528	2028	85000	68000	52000
552	2030	85000	68000	52000

Table II-14 Percentage of south facing houses with photovoltaics installed required to match green electricity demand for three tariff levels

Month number	Year	Percentage of south facing houses with PV		
		2% tariff	8% tariff	15% tariff
0	1984	0	0	0
24	1986	0	0	0
48	1988	0	0	0
72	1990	0	0	0
96	1992	0	0	0
120	1994	0	0	0
144	1996	0	0	0
168	1998	0	0	0
192	2000	0	0	0
216	2002	0	0	0
240	2004	0.04	0.04	0.04
264	2006	0.1	0.1	0.1
288	2008	0.15	0.15	0.15
312	2010	0.2	0.2	0.2
336	2012	0.3	0.3	0.3
360	2014	0.4	0.4	0.4
384	2016	0.5	0.5	0.5
408	2018	0.6	0.6	0.6
432	2020	0.7	0.7	0.7
456	2022	0.8	0.8	0.8
480	2024	0.9	0.9	0.9
504	2026	1.0	1.0	1.0
528	2028	1.0	1.0	1.0
552	2030	1.0	1.0	1.0

Table II-15 Bio supply to CHP required to match green electricity demand for three tariff levels

Month number	Year	Biomass supply		
		2% tariff	8% tariff	15% tariff
0	1984	0	0	0
24	1986	0	0	0
48	1988	0	0	0
72	1990	0	0	0
96	1992	0	0	0
120	1994	0	0	0
144	1996	0	0	0
168	1998	0	0	0
192	2000	0	0	0
216	2002	0	0	0
240	2004	0.1	0.1	0.1
264	2006	0.2	0.2	0.2
288	2008	0.3	0.3	0.3
312	2010	0.4	0.4	0.4
336	2012	0.5	0.5	0.5
360	2014	0.6	0.6	0.6
384	2016	0.7	0.7	0.7
408	2018	0.8	0.8	0.8
432	2020	0.9	0.9	0.9
456	2022	1.0	1.0	1.0
480	2024	1.0	1.0	1.0
504	2026	1.0	1.0	1.0
528	2028	1.0	1.0	1.0
552	2030	1.0	1.0	1.0

Table II-16 Size of CHP available required to match green electricity demand for three tariff levels

Month number	Year	Size of CHP		
		2% tariff	8% tariff	15% tariff
0	1984	0	0	0
12	1985	0	0	0
24	1986	0	0	0

Month number	Year	Size of CHP		
36	1987	0	0	0
48	1988	0	0	0
60	1989	0	0	0
72	1990	0	0	0
84	1991	0	0	0
96	1992	0	0	0
108	1993	0	0	0
120	1994	0	0	0
132	1995	160	160	160
144	1996	400	400	400
156	1997	626	626	626
168	1998	986	986	986
180	1999	1300	1300	1300
192	2000	1550	1550	1550
204	2001	1850	1850	1850
216	2002	2000	2000	2000
228	2003	2000	2000	2000
240	2004	2500	2500	2500
252	2005	3000	3000	3000
264	2006	3500	3500	3500
276	2007	4000	4000	4000
288	2008	4500	4500	4500
300	2009	5000	5000	5000
312	2010	5500	5500	5500
324	2011	6000	6000	6000
336	2012	7000	7000	7000
348	2013	8000	8000	8000
360	2014	9000	9000	9000
372	2015	10000	10000	10000
384	2016	12000	12000	12000
396	2017	14000	14000	14000
408	2018	16000	16000	16000
420	2019	18000	18000	18000
432	2020	20000	20000	20000
444	2021	24000	24000	24000
456	2022	25000	25000	25000
468	2023	25000	25000	25000
480	2024	25000	25000	25000
492	2025	25000	25000	25000

II.2.2 Two percent equal contribution

Table II-17 Number of turbines installed for a two percent tariff scenario with equal technology contribution

Month number	Year	Number of turbines
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	10
264	2006	20
288	2008	30
312	2010	30
336	2012	30
360	2014	30
384	2016	30
408	2018	30
432	2020	30
456	2022	30
480	2024	30
504	2026	30
528	2028	30
552	2030	30

Table II-18 Biomass supply to boiler for a two percent tariff scenario with equal technology contribution

Month number	Year	Biomass supply
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.1
264	2006	0.2
288	2008	0.3
312	2010	0.4
336	2012	0.5
360	2014	0.6
384	2016	0.7
408	2018	0.8
432	2020	0.9
456	2022	1.0
480	2024	1.0
504	2026	1.0
528	2028	1.0
552	2030	1.0

Table II-19 Size of combined heat and power plant available for a two percent tariff scenario with equal technology contribution

Month number	Year	Size of CHP
0	1984	0
12	1985	0
24	1986	0
36	1987	0
48	1988	0
60	1989	0
72	1990	0

Month number	Year	Size of CHP
84	1991	0
96	1992	0
108	1993	0
120	1994	0
132	1995	160
144	1996	400
156	1997	626
168	1998	986
180	1999	1300
192	2000	1550
204	2001	1850
216	2002	2000
228	2003	2000
240	2004	2500
252	2005	3000
264	2006	3500
276	2007	4000
288	2008	4500
300	2009	5000
312	2010	5500
324	2011	6000
336	2012	7000
348	2013	8000
360	2014	9000
372	2015	10000
384	2016	12000
396	2017	14000
408	2018	16000
420	2019	18000
432	2020	20000
444	2021	24000
456	2022	25000
468	2023	25000
480	2024	25000
492	2025	25000

Table II-20 Hydro installed for a two percent tariff scenario with equal technology contribution

Month number	Year	Hydro installed (kW)
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	200
264	2006	500
288	2008	1000
312	2010	3000
336	2012	6000
360	2014	10000
384	2016	20000
408	2018	22000
432	2020	22000
456	2022	220000
480	2024	22000
504	2026	22000
528	2028	22000
552	2030	22000

Table II-21 Percentage of south facing suitable houses with photovoltaic installed for a two percent tariff scenario with equal technology contribution

Month number	Year	Percentage of south facing houses with PV
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.04
264	2006	0.1
288	2008	0.15
312	2010	0.2
336	2012	0.3
360	2014	0.4
384	2016	0.5
408	2018	0.6
432	2020	0.7
456	2022	0.8
480	2024	0.85
504	2026	0.85
528	2028	0.85
552	2030	0.85

II.2.3 Eight percent equal contribution

Table II-22 Number of turbines installed for an eight percent tariff scenario with equal technology contribution

Month number	Year	Number of turbines
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	10
264	2006	18
288	2008	18
312	2010	18
336	2012	18
360	2014	18
384	2016	18
408	2018	18
432	2020	18
456	2022	18
480	2024	18
504	2026	18
528	2028	18
552	2030	18

Table II-23 Biomass supply to boiler for an eight percent tariff scenario with equal technology contribution

Month number	Year	Biomass supply
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.1
264	2006	0.2
288	2008	0.3
312	2010	0.4
336	2012	0.5
360	2014	0.6
384	2016	0.7
408	2018	0.8
432	2020	0.9
456	2022	1.0
480	2024	1.0
504	2026	1.0
528	2028	1.0
552	2030	1.0

Table II-24 Size of combined heat and power plant available for an eight percent tariff scenario with equal technology contribution

Month number	Year	Size of CHP
0	1984	0
12	1985	0
24	1986	0
36	1987	0
48	1988	0
60	1989	0
72	1990	0

Month number	Year	Size of CHP
84	1991	0
96	1992	0
108	1993	0
120	1994	0
132	1995	160
144	1996	400
156	1997	626
168	1998	986
180	1999	1300
192	2000	1550
204	2001	1850
216	2002	2000
228	2003	2000
240	2004	2500
252	2005	3000
264	2006	3500
276	2007	4000
288	2008	4500
300	2009	5000
312	2010	5500
324	2011	6000
336	2012	7000
348	2013	8000
360	2014	9000
372	2015	10000
384	2016	12000
396	2017	14000
408	2018	16000
420	2019	18000
432	2020	18000
444	2021	18000
456	2022	18000
468	2023	18000
480	2024	18000
492	2025	18000

Table II-25 Hydro installed for an eight percent tariff scenario with equal technology contribution

Month number	Year	Hydro installed (kW)
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	200
264	2006	500
288	2008	1000
312	2010	3000
336	2012	6000
360	2014	10000
384	2016	15000
408	2018	17000
432	2020	17000
456	2022	17000
480	2024	17000
504	2026	17000
528	2028	17000
552	2030	17000

Table II-26 Percentage of south facing suitable houses with photovoltaic installed for an eight percent tariff scenario with equal technology contribution

Month number	Year	Percentage of south facing houses with PV
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.1
264	2006	0.2
288	2008	0.3
312	2010	0.4
336	2012	0.5
360	2014	0.6
384	2016	0.65
408	2018	0.65
432	2020	0.65
456	2022	0.65
480	2024	0.65
504	2026	0.65
528	2028	0.65
552	2030	0.65

II.2.4 Fifteen percent equal contribution

Table II-27 Number of turbines installed for a fifteen percent tariff scenario with equal technology contribution

Month number	Year	Number of turbines
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	5
264	2006	10
288	2008	15
312	2010	18
336	2012	18
360	2014	18
384	2016	18
408	2018	18
432	2020	18
456	2022	18
480	2024	18
504	2026	18
528	2028	18
552	2030	18

Table II-28 Biomass supply to boiler for a fifteen percent tariff scenario with equal technology contribution

Month number	Year	Biomass supply
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.1
264	2006	0.2
288	2008	0.3
312	2010	0.4
336	2012	0.5
360	2014	0.6
384	2016	0.7
408	2018	0.8
432	2020	0.9
456	2022	1.0
480	2024	1.0
504	2026	1.0
528	2028	1.0
552	2030	1.0

Table II-29 Size of combined heat and power plant available for a fifteen percent tariff scenario with equal technology contribution

Month number	Year	Size of CHP
0	1984	0
12	1985	0
24	1986	0
36	1987	0
48	1988	0
60	1989	0
72	1990	0

Month number	Year	Size of CHP
84	1991	0
96	1992	0
108	1993	0
120	1994	0
132	1995	160
144	1996	400
156	1997	626
168	1998	986
180	1999	1300
192	2000	1550
204	2001	1850
216	2002	2000
228	2003	2000
240	2004	2500
252	2005	3000
264	2006	3500
276	2007	4000
288	2008	4500
300	2009	5000
312	2010	5500
324	2011	6000
336	2012	7000
348	2013	8000
360	2014	9000
372	2015	10000
384	2016	12000
396	2017	12000
408	2018	12000
420	2019	12000
432	2020	12000
444	2021	12000
456	2022	12000
468	2023	12000
480	2024	12000
492	2025	12000

Table II-30 Hydro installed for a fifteen percent tariff scenario with equal technology contribution

Month number	Year	Hydro installed (kW)
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	200
264	2006	500
288	2008	1000
312	2010	3000
336	2012	6000
360	2014	10000
384	2016	10000
408	2018	10000
432	2020	10000
456	2022	12000
480	2024	12000
504	2026	12000
528	2028	12000
552	2030	12000

Table II-31 Percentage of south facing suitable houses with photovoltaic installed for a fifteen percent tariff scenario with equal technology contribution

Month number	Year	Percentage of south facing houses with PV
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.1
264	2006	0.2
288	2008	0.3
312	2010	0.4
336	2012	0.5
360	2014	0.5
384	2016	0.5
408	2018	0.5
432	2020	0.5
456	2022	0.5
480	2024	0.5
504	2026	0.5
528	2028	0.5
552	2030	0.5

II.2.5 Equal contribution mix to meet low growth in green tariff uptake

Table II-32 Number of turbines installed for equal technology contribution and low green tariff uptake

Month number	Year	Number of turbines
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	1
264	2006	1
288	2008	2
312	2010	2
336	2012	4
360	2014	5
384	2016	6
408	2018	7
432	2020	8
456	2022	9
480	2024	10
504	2026	11
528	2028	11
552	2030	11

Table II-33 Biomass supply to boiler for equal technology contribution and low green tariff uptake

Month number	Year	Biomass supply
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.1
264	2006	0.2
288	2008	0.3
312	2010	0.4
336	2012	0.5
360	2014	0.6
384	2016	0.7
408	2018	0.8
432	2020	0.9
456	2022	1.0
480	2024	1.0
504	2026	1.0
528	2028	1.0
552	2030	1.0

Table II-34 Size of combined heat and power plant available for equal technology contribution and low green tariff uptake

Month number	Year	Size of CHP
0	1984	0
12	1985	0
24	1986	0
36	1987	0
48	1988	0
60	1989	0
72	1990	0
84	1991	0

Month number	Year	Size of CHP
96	1992	0
108	1993	0
120	1994	0
132	1995	160
144	1996	400
156	1997	626
168	1998	986
180	1999	1300
192	2000	1550
204	2001	1850
216	2002	2000
228	2003	2300
240	2004	2600
252	2005	3000
264	2006	3000
276	2007	3000
288	2008	3000
300	2009	3200
312	2010	3200
324	2011	3500
336	2012	3800
348	2013	4000
360	2014	4000
372	2015	4500
384	2016	4500
396	2017	4500
408	2018	5000
420	2019	5000
432	2020	5000
444	2021	5500
456	2022	5500
468	2023	5500
480	2024	6000
492	2025	6000

Table II-35 Hydro installed for equal technology contribution and low green tariff uptake

Month number	Year	Hydro installed (kW)
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	500
264	2006	600
288	2008	900
312	2010	1000
336	2012	1900
360	2014	2400
384	2016	3100
408	2018	3600
432	2020	4900
456	2022	6400
480	2024	7000
504	2026	8000
528	2028	8000
552	2030	8000

Table II-36 Percentage of south facing suitable houses with photovoltaic installed for equal technology contribution and low green tariff uptake

Month number	Year	Percentage of south facing houses with PV
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.02
264	2006	0.04
288	2008	0.05
312	2010	0.07
336	2012	0.10
360	2014	0.13
384	2016	0.17
408	2018	0.20
432	2020	0.22
456	2022	0.26
480	2024	0.26
504	2026	0.27
528	2028	0.27
552	2030	0.27

II.2.6 Equal contribution mix to meet high growth in green tariff uptake

Table II-37 Number of turbines installed for equal technology contribution and high green tariff uptake

Month number	Year	Number of turbines
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	2
264	2006	4
288	2008	5
312	2010	6
336	2012	10
360	2014	10
384	2016	11
408	2018	12
432	2020	13
456	2022	14
480	2024	14
504	2026	14
528	2028	14
552	2030	14

Table II-38 Biomass supply to boiler for equal technology contribution and high green tariff uptake

Month number	Year	Biomass supply
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.15
264	2006	0.3
288	2008	0.6
312	2010	1.0
336	2012	1.0
360	2014	1.0
384	2016	1.0
408	2018	1.0
432	2020	1.0
456	2022	1.0
480	2024	1.0
504	2026	1.0
528	2028	1.0
552	2030	1.0

Table II-39 Size of combined heat and power plant available for equal technology contribution and high green tariff uptake

Month number	Year	Size of CHP
0	1984	0
12	1985	0
24	1986	0
36	1987	0
48	1988	0
60	1989	0
72	1990	0
84	1991	0

Month number	Year	Size of CHP
96	1992	0
108	1993	0
120	1994	0
132	1995	160
144	1996	400
156	1997	626
168	1998	986
180	1999	1300
192	2000	1550
204	2001	1850
216	2002	2000
228	2003	3000
240	2004	4000
252	2005	4300
264	2006	4600
276	2007	4600
288	2008	4600
300	2009	4800
312	2010	4800
324	2011	4800
336	2012	5500
348	2013	5500
360	2014	6000
372	2015	6500
384	2016	7000
396	2017	7500
408	2018	8000
420	2019	8000
432	2020	8000
444	2021	8200
456	2022	8200
468	2023	8300
480	2024	8300
492	2025	8500

Table II-40 Hydro installed for equal technology contribution and high green tariff uptake

Month number	Year	Hydro installed (kW)
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	650
264	2006	1200
288	2008	2400
312	2010	3200
336	2012	5300
360	2014	5600
384	2016	6000
408	2018	7000
432	2020	8000
456	2022	9000
480	2024	9000
504	2026	9000
528	2028	9000
552	2030	9000

Table II-41 Percentage of south facing suitable houses with photovoltaic installed for equal technology contribution and high green tariff uptake

Month number	Year	Percentage of south facing houses with PV
0	1984	0
24	1986	0
48	1988	0
72	1990	0
96	1992	0
120	1994	0
144	1996	0
168	1998	0
192	2000	0
216	2002	0
240	2004	0.05
264	2006	0.1
288	2008	0.15
312	2010	0.17
336	2012	0.25
360	2014	0.3
384	2016	0.35
408	2018	0.37
432	2020	0.4
456	2022	0.4
480	2024	0.4
504	2026	0.4
528	2028	0.4
552	2030	0.4

Table II-42 Green electricity demand for the low growth and high growth green tariff uptake models

Year	Annual rolling demand (billions)	Low growth green electricity demand (billions)	High growth green electricity demand (billions)
2002	2,254,173	4,276.30	4,276.30
2003	2,307,903	10,013.66	15,649.09
2004	2,362,327	16,020.99	27,560.50
2005	2,415,918	22,300.59	40,018.04
2006	2,469,339	28,843.66	65,082.43
2007	2,523,453	35,653.88	91,214.00
2008	2,578,170	42,742.74	118,446.33
2009	2,628,911	50,105.17	146,786.55
2010	2,677,670	57,657.92	175,958.91
2011	2,726,926	72,114.89	205,998.39
2012	2,776,724	87,075.39	237,056.32
2013	2,829,248	102,552.59	255,272.41
2014	2,883,553	118,640.19	274,248.83
2015	2,938,470	135,334.34	293,929.75
2016	2,993,987	152,603.27	314,219.12
2017	3,047,594	170,450.75	335,120.04
2018	3,100,316	188,737.12	356,354.79
2019	3,153,565	207,503.04	378,020.42
2020	3,207,053	226,833.52	384,511.77
2021	3,245,695	246,686.25	391,003.63
2022	3,276,012	265,870.39	395,698.19
2023	3,306,567	276,543.74	399,394.19
2024	3,337,280	287,389.21	403,119.06
2025	3,364,439	298,394.54	406,856.14

Appendix III: List of publications arising from this research

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